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NATIONAL BUREAU OF STANDARDS REPORT

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A STUDY OF A CEILING PANEL HEATING SYSTEM

by

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Report to
Housing and Home Finance Agency
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Abstract

The performance characteristics of a ceiling panel heating system were studied by means of a full scale installation in the Test Bungalow to complete the current investigation of heating systems for small houses for the Housing and Home Finance Agency. The entire ceiling area of the five rooms of the Test Bungalow was equipped with heating coils of nominal 3/8-inch copper tubing spaced on 4-inch centers and divided into 10 circuits. The water flow rate in each circuit could be regulated independently by means of a throttling valve. An electrically-heated boiler permitted accurate measurement of the total heat input to the ceiling panel, and twenty heat flow meters above the panel provided measurements of the reverse heat loss to the attic. Thus the downward heat emission of the panel could be determined with considerable accuracy and could be correlated with the average ceiling surface temperature as measured by an extensive thermocouple system.

The observed data showed that the heat emission of the panel ranged from 25 Btu/hr (sq ft) for an average ceiling surface temperature of 93.5°F to 49 Btu/hr (sq ft) for an average ceiling surface temperature of 112°F. Values published in the 1954 Guide of the American Society of Heating and Ventilating Engineers for the same range of ceiling surface temperature and at corresponding values of unheated mean radiant temperature are about 37 and 68 Btu/hr (sq ft), respectively. The Guide values are computed from separate radiation and convection equations. The ceiling panel output was also correlated with the average water temperature in the coils. The heat loss of the Test Bungalow was not excessive with the ceiling panel system and was about the same as that observed for a baseboard convector system in the same structure. The reverse heat loss to the attic ranged from 17.4 percent of the total panel output with 2.7 in. of insulation on the ceiling to 11.6 percent for double that thickness. The house was heated comfortably for outdoor temperatures of -20°F, a condition for which the heat loss of the house was about 61 Btu/hr (sq ft) of floor area. Open louvers in the attic increased the infiltration rate in the living space from 30 to 35 percent.

1. INTRODUCTION

As a part of the program of investigation of heating systems for small dwellings for the Housing and Home Finance Agency, observations were made on the performance characteristics of a ceiling panel heating system in the Test Bungalow using a hot water piping circuit embedded in plaster.

The program was planned to provide test data on the following characteristics of the heating system:

(a) The gross heat output required from the system to maintain predetermined temperatures in the living space.

(b) The relation between ceiling surface temperature and the heat emission of the panels.

(c) The relation between water temperature in the heating circuit and ceiling surface temperature.

(d) The reverse loss from the heated ceiling to the attic for two degrees of insulation of the ceiling.

(e) The variations of ceiling surface temperature between adjacent pipes in the heating circuit.

(f) The variation of temperature with height above the floor and the temperature variations from room to room for a range of outdoor temperature.

(g) The effect of basement temperature on the floor surface temperature in the living space.

(h) The control of room temperature attained with several methods of control.

(i) The rate of rise of room temperature under pickup conditions.

(j) The effect of ventilating the attic on the heat loss of the house.

2. DESCRIPTION OF SYSTEM

Panels

The panel areas employed 3/8-inch nominal diameter type L, bench formed, sinuous coils spaced on 4-inch centers and mounted under expanded lath. The coils and lath were supported independently. The ceiling was plastered in three coats to 3/4-inch grounds and keyed to the metal lath. The total effective length of the 10 separate coils was approximately 1600 feet. A balanced temperature

in the five rooms was obtained by the adjustment of valves located near the boiler inlet which controlled the flow in each of the separate 10 coil returns. The quantity of water in the coils was calculated to be 10 gallons. Figs. 1 through 4 show several views of the coils before plastering. The method of supporting the copper tubes is shown in Fig. 1. The valves in the return lines from the ten circuits are shown just below the ceiling level in Fig. 2 and the notching of the ceiling joists in the hall to accommodate some of the mains is visible in Figs. 2 and 3. The method of making the connection between the supply main and each individual circuit is shown in Fig. 4.

Boiler

An experimental hot water boiler was used to supply hot water to the system. The boiler was constructed of five hairpin type immersion electric heaters and a cylindrical shell 60 inches by 10 inches. The amount of electrical energy supplied to the heaters was integrated by calibrated watthour meters. The maximum heater capacity energized during any of the tests was 15 K.W. The control panel for the heating system is shown in Fig. 5.

The water was circulated by means of a 1-1/4 inch high velocity booster pump driven by a 1/6 H.P. motor. A mercury manometer connected to the inlet and discharge connection of the pump registered the equivalent of 9.6 feet of water. The rate of water flow was calculated to be approximately 6 gallons per minute.

The expansion tank was located directly above the boiler with its upper surface immediately below ceiling level. Fig. 6, taken before installation of the expansion tank, controls and insulation, shows the boiler pump and return connections. The boiler held approximately 10 gallons of water, the expansion tank below the air vent, 5 gallons.

3. TEST EQUIPMENT

The Test Bungalow was extensively remodeled previous to this series of tests. A plastered ceiling which incorporated a panel heating system was installed. New ceiling joists were placed at the eight foot level and fire stops provided in the stud spaces at the ceiling level. Copper tubing was fastened under expanded metal lath which was applied to the ceiling joists. Several openings in the floor for warm air registers were repaired to conform with the original equipment, fluorescent illumination was provided, new plasterboard was installed on the inner wall surfaces and the entire structure was repainted. A photograph of the Test Bungalow is shown in the upper part of Fig. 7 and the enclosure built around the Test Bungalow to allow control of its exterior temperatures is shown in the lower part of Fig. 7.

Significant construction features of the Test Bungalow which

remained unchanged and which have been described for other heating systems tested recently were as follows: weatherstripped windows and doors, uninsulated outside walls, basement ceiling consisted of 1-inch rigid insulation board nailed directly to the underside of the floor joists. Fig. 8 is a floor plan of the Test Bungalow showing the arrangement and size of the four rooms and bath.

The ceiling was insulated from the attic space with one layer of commercial "double thick" rock wool. An equal second layer was later installed. The effective thickness of one layer of rock wool was determined to be 2.7 inches.

The temperature distribution was ascertained by means of 200 newly-installed thermocouples enclosed in 3-inch cork spheres located at five stations and five levels in each of the four large rooms and at other suitable stations on the floor, sidewalls, and in basement, attic and out-of-doors. An additional 400 thermocouples were installed to measure the following temperatures: inlet and outlet water to separate coils, upper and lower window surfaces, and ceiling surface temperatures at 2-inch intervals. The thermocouples on the ceiling surface were installed directly beneath each copper tube and midway between the copper tubes on a transverse line half way between the extremities of each ceiling panel.

The absolute values of the heat emitted in a downward and upward direction from the coil surface area were determined with the aid of twenty heat flow meters placed over the first layer of rock wool insulation in the attic. Two heat flow meters were installed over each heating coil and located so each was centrally located in half the area of the coil.

4. TEST PROCEDURE

Forty-four tests were made to determine the performance of the panel heating system for a range of outdoor temperature from -20°F to 50°F. Other variables during the series of tests were the amount of ceiling insulation used, the ventilation of the attic, the type of control system for boiler and pump, the room temperature maintained indoors, and the rate of water circulation in the system.

After several days of preliminary operation which served to cure the plaster, adjustments were made to obtain approximately equal temperatures in all rooms. A proper temperature balance between the several rooms at the 30-inch level was difficult to obtain. The ten valves located in the ten ceiling coil return lines were used to adjust the flow in obtaining the desired balance. It was necessary to shut off the entire flow of water to one of the three coils in the living room. Thus, two panels in each of the four larger rooms and one in the bath were in operation with the exception of tests 1-4. In these tests, conducted at the beginning of the investigation, horizontal temperature balance was achieved in tests 1, 3 and 4 when the water

to the west coil in the south bedroom was almost completely restricted. In test 2 the panel in the bathroom was not heated. It had been anticipated that less than the entire ceiling surface would be required to warm the living room adequately. However, the entire ceiling area in each room was provided with heating coils to provide the maximum degree of choice in the panel location. Table 1 summarizes the area heated by each of the ten heating coils and the panel area in each room of the house.

After the desired outdoor, indoor and basement temperatures were maintained for a period of 12 hours or more, the attic temperature became steady. Data were then recorded for the next 12 to 18 hours. Observations of the temperatures within the living area for approximately 230 stations, 304 ceiling surface temperatures spaced at two inch intervals, and the output of 20 heat flow meters located in the attic space were recorded at four-hour intervals. The wet and dry bulb readings as measured by a sling psychrometer were also recorded every four hours.

Hourly recordings were made of the following temperatures: outside air, 30-inch level at five room centers, five positions in the basement, boiler inlet water, boiler outlet water and two positions in the attic. The accuracy of the temperature measuring circuits was checked every hour with the temperature of melting ice used as a standard. In addition temperatures at a reference point were observed every four hours by means of the electronic indicator, electronic recorder and a hand-operated potentiometer. Electrical energy supplied to the boiler heaters, circulating pump and for house illumination were recorded hourly.

5. CONTROL SYSTEMS

Several control systems were tried to determine which provided suitable room temperature control for a ceiling panel heating system. Tests 1 to 18 were conducted under approximately steady state conditions in which the heat input to the boiler was adjusted to a value very nearly equal to the heat loss of the house. This was accomplished by means of continuously energized heaters, supplemented by a relatively small amount of thermostatted heating capacity which maintained constant boiler water temperature within ±0.9°F and compensated for variations in line voltage on the electric heaters. The circulating pump operated continuously during these tests.

Tests 19 through 28 were also conducted with the circulating pump running continuously but with one of two thermostats in the living room regulating the temperature by intermittently energizing heaters with a capacity of 45,420 Btu per hour.

The living room thermostat controlled the heaters in the boiler during tests 29 and 30. Pump action depended on boiler water tem-

perature and was controlled by an aquastat. In tests 29 and 30 the pump was energized when the boiler water temperature reached 110°F and 160°F, respectively.

In tests 31-33, the room temperature was regulated by the living room thermostat which cycled the pump and heater simultaneously.

Tests 34 to 37 simulated operation that would be used when domestic hot water was to be heated by the boiler. The aquastat in the boiler controlled the electric heaters to produce a boiler water temperature of 160°F and the living room thermostat controlled the operation of the circulating pump.

In tests 38-44, the pump circulated the water in response to the thermostat located in the living room. The temperature of the boiler water was raised 1°F for each 1°F drop in outside temperature by the action of an outdoor reset control.

6. HEAT LOSS OF THE STRUCTURE

A summary of some of the important results of the tests is shown in Table 2. Data from this table were plotted in Fig. 9 to show the relation between the heat loss of the structure and the indoor-outdoor temperature difference for three different sets of operating conditions. The heat required to maintain a globe-thermometer temperature of 70°F at the 30-inch level is shown to be the lowest during steady state conditions for which the circulating pump was operated continuously and the heat input was continuous and equal to the heat loss of the structure. The data in Table 2 show that the heat requirements were equally small when an electric room-type thermostat in the living room controlled the operation of the boiler.

Fig. 9 shows that the heat loss of the structure was a little higher than for the operating conditions previously described when the boiler water was maintained at a temperature suitable for heating domestic hot water. About the same heat loss occurred when the boiler water temperature was modulated by an outdoor reset control and the room thermostat controlled the pump operation.

The upper curve in Fig. 9 shows the effect of opening the gable louvers in the attic for ventilation. Attic ventilation increased the heat loss of the structure about 1500 Btu/hr for an outdoor temperature of 30°F, whereas the increase was about 4500 Btu/hr for an outdoor temperature of 0°F. This increase is attributed primarily to an increase in infiltration of air as a result of chimney action in the structure. Measurements of the infiltration rate with a helium katharometer showed that the air leakage in the living space increased from 30 to 35 percent when the attic louvers were opened for otherwise comparable conditions. The data in Table 2 show that the attic temperature was warmer with the attic louvers open than when they were closed, indicating that an increased air movement was occurring upward through the structure.

Tests 6, 9 and 10 were conducted with equal outdoor temperatures but with basement temperatures of 37.8°F, 49.5°F, and 59.2°F, respectively. When warmer basement temperatures were maintained the heat requirements were approximately 10% less. A greater effect was noticed when the temperature was raised from 37.8°F to 49.5°F than from 49.5°F to 59.2°F. This was due in part to the fact that the temperature at the 30-inch level was maintained at 70.9°F for test 10 as compared with 70.0°F for tests 6 and 9. This variation of 0.9°F would tend to make the heat requirement of test 10 approach that of test 9. A decrease in heat loss through the floor of about 2000 Btu/hr would be expected as a result of raising the basement temperature from 38°F to 60°F.

In addition to the heat output from the panel area an average of 0.33 K.W. of electrical energy for illumination and instrument power and from 0.02 to 0.17 K.W. of electrical energy for the circulating pump were dissipated. This electrical energy contributed from 1200 to 1700 Btu per hour to the heat requirements. Also included was the 400 Btu per hour body heat of one operator.

7. HEAT EMISSION FROM THE CEILING PANEL

The heat emitted downward from the panel was computed by subtracting the reverse heat loss to the attic, as indicated by the twenty heat flow meters, from the total electrical input to the boiler including sixty percent of the pump energy. The heated panel extended one-half the coil spacing (2 inches) beyond the last heated tube.

The unit heat emission thus determined is plotted in Fig. 10 against the average ceiling surface temperature for tests 1 to 8 inclusive at steady state operating conditions. Fig. 10 indicates this relationship to be linear with the heat emission rate ranging from 25 Btu/hr (sq ft) for an average ceiling temperature of 93.5°F to 65 Btu/hr (sq ft) for an average ceiling temperature of 124.5°F. The data in Table 2 further indicate that raising the globe thermometer temperature at the 30-inch level from 70°F to 75°F decreased the panel output from 5 to 7.5 Btu/hr (sq ft) for the same ceiling temperature.

Fig. 10 also indicates that the relationship between average water temperature in the coils and the heat output of the panel was linear for the range of these tests. The heat emission from the panel ranged from 25 Btu/hr (sq ft) for an average water temperature of about 102°F to 65 Btu/hr (sq ft) for an average water temperature of about 143°F.

Fig. 10 shows that the difference between average water temperature and average ceiling temperature ranged from 8 deg F for a heat emission rate of 25 Btu/hr (sq ft) to 19 deg F for a heat emission rate of 65 Btu/hr (sq ft).

The heat loss upward to the attic through the single blanket of mineral wool insulation ranged from 15.9 percent to 19.3 percent of the total heat input to the panel. The average for all tests with a single blanket of insulation was 17.4 percent. Upon the addition of an equal second layer of mineral wool the reverse loss averaged 11.6 percent of the total heat input to the panel.

It will be noted in Table 2 that the reverse heat loss indicated by the heat flow meters was less with the attic ventilated than with the louvers closed. This would be expected because the attic temperature was increased by opening the attic louvers. It also supports the opinion that more warm air moved from the living space to the attic with the louvers open.

8. CEILING SURFACE TEMPERATURES

Figs. 11-15 show the ceiling surface temperatures in each of the five rooms as measured at 2-inch intervals on a transverse line across the center of the room at right angles to the direction of water flow in the tubes. A thermocouple was located beneath each heated tube and one midway between each adjacent pair. These figures show the maximum variation of temperature that existed on the ceiling surface. There were some variations in amplitude between rooms indicating possible differences in plaster thickness, bonding, etc.

Figs. 11-15 indicate little temperature drop between inlet and outlet of the coils in the kitchen, north bedroom, and bath because these circuits were wide open to permit a maximum water flow. The panels in these three rooms were the most heavily loaded. The coils in the living room and south bedroom were throttled causing a more significant temperature drop between inlet and outlet of the coils. These figures show that the ceiling surface temperature decreased rapidly 2 inches from the last heated tube at the edge of the panel. The data in Figs. 11-15 were observed during test 16 at an outdoor temperature of 15°F and with a double layer of insulation on the ceiling.

The average ceiling surface temperature for each of the nine heated coils and the weighted average for each room and for the whole house is summarized in Table 3 for all of the tests made at steady state conditions. These data show some variation of ceiling temperature in different rooms and indicate also that the kitchen, north bedroom, and bath required the highest ceiling temperatures to maintain the desired room temperature. The weighted average ceiling temperature for the whole house was determined by weighting the average surface temperature of each coil for its proportion of the total heated panel area. Some changes in adjustment of the valves in the coil outlets were made during the first four tests to obtain the desired balance of temperature in the five rooms.

9. TEMPERATURE DISTRIBUTION

The temperature distribution produced in the Test Bungalow by the ceiling panel heating system during ten tests are summarized in Tables 4-13 inclusive. These tables show the average temperatures at five levels in each room under steady state conditions for a range of outdoor temperatures from -20°F to 32°F. Three groups of tests show the temperature distribution with a single blanket of insulation on the ceiling, with a double blanket of insulation on the ceiling, and with attic ventilation, respectively. The water flow in the various heating circuits was adjusted to approximate equal temperatures at the 30-inch level at the center of all rooms. Tables 4-13 show that the maximum difference between any two rooms at the 30-inch level was less than 2°F in all but one test. The variations in temperature between rooms at other levels were usually greater than at the 30-inch level.

The relation between indoor-outdoor temperature difference and the vertical temperature difference in the house is shown in Fig. 16 for eight tests at steady state conditions. These curves show that the vertical temperature difference in the living zone, from 2 to 60 inches above the floor ranged from 6°F at an outdoor temperature of 32°F to 12°F for an outdoor temperature of -20°F. The corresponding temperature differences between the 2 and 94 inch levels were 14°F and 33.5°F, respectively. The change in vertical temperature difference in the living zone was negligible when an electric room thermostat was used to control the boiler operation, but the 2 to 94 inch temperature differences were increased 1 or 2 degrees. The vertical temperature differences observed in this same structure with a baseboard convector heating system are shown in Fig. 16 for comparison. The average vertical temperature differences for the whole house are reported for all tests in Table 2.

Significant changes in vertical temperature differences were observed in tests 6, 9, and 10 when the basement temperatures were maintained at 38°F, 50°F, and 59°F, respectively, by independent means. The corresponding average vertical temperature differences in the living zone were 9.8°F, 8.7°F, and 8.5°F, respectively, and from 2 to 94 inches above the floor were 26.4°F, 23.3°F, and 22.9°F, respectively.

Test number 11 was conducted with the main boiler return restricted, which resulted in a 22.7°F temperature drop across the coils. Test number 6 was conducted under similar conditions with the exception of the water flow restriction. A difference of 9.9°F was observed between the temperature of the coil inlet and coil outlet for the test. The restricted flow or additional temperature drop resulted in only a slight increase in maximum horizontal temperature difference and average vertical temperature difference.

Fig. 17 shows the pattern of air temperature from floor to ceiling in the center of the living room as measured by 16 bare

30-gage thermocouples spaced at intervals at this station. These curves show that the floor surface temperature was about 5°F higher than the air temperature 2 or 3 inches above the floor. Between the levels 6 inches and 90 inches above the floor the gradient was quite uniform at about 2.5 degrees per foot of height. The layer of hot air adjacent to the ceiling was less than 6 inches thick.

Fig. 18 shows the effect of basement temperature on the floor surface temperature in the living room along a line from the center of the double windows to the opposite wall. The last 36 inches near the inside wall was a concrete hearth for the fireplace. It will be observed that raising the air temperature below the floor joists 22°F raised the floor surface temperature only 1 or 2 degrees over a large area of the floor. The temperature of a border 18-inches wide adjacent to the outside wall was raised about 5°F.

Fig. 19 illustrates that chairs shield the floor from the radiant heat emitted by the ceiling. Placing a chair over the floor thermocouples lowered the floor surface temperatures about 4°F. This shielding effect would not be of great significance with respect to chairs, but the floor area under a desk or dining table might become undesirably cold when the ceiling radiation was excluded. Fig. 17 and Fig. 19 suggest that horizontal surfaces above the floor level might be warmed several degrees above air temperature by the radiant heat from the ceiling.

10. ROOM TEMPERATURE CONTROL

Several methods of controlling the operation of the heating system in response to changes in room temperature were tried as described under Control Systems. Two types of room thermostat were used for all except special thermostat tests. Both types opened the control circuit on a rise in temperature. One was a two-wire thermostat in which a magnet-type mercury switch was actuated by a spiral bimetallic element; the other was a three-wire thermostat of the anticipating type employing a bimetallic element. The thermostats were located at the 30-inch level on the east interior wall of the living room.

Fig. 20 shows the regulation maintained by a control system which would be expected to have the greatest thermal lag of the various systems tried. The heaters in the boiler were energized by the two-wire thermostat in the living room through a relay. Pump operation was controlled by an aquastat in the boiler. The aquastat was set to start the pump when the boiler water reached 158°F. The temperatures plotted in Fig. 20 were observed at the 30-inch level in the centers of the living room and north bedroom using an electronic recorder and unshielded thermocouples of 30-gage wire. With this method of control the living room temperature varied between 69.1°F and 69.9°F whereas the north bedroom temperature varied from 70.9°F to 71.5°F during the same period.

All other methods of control tried during this investigation provided close regulation of the room temperature for any given outdoor temperature and were considered satisfactory from the standpoint of lag in response.

11. PICKUP CHARACTERISTICS

The behavior of the panel heating system was studied at an outdoor temperature of 32°F when one form of night setback of the thermostat was used. The living room thermostat was lowered to 60°F for a period of 8 hours during which the interior doors of the house were closed and the bedrooms were ventilated by opening the windows. At the conclusion of 8 hours which simulated the sleeping time of the occupants, their actions upon arising were also predicted. The windows were closed, the inside doors opened and the thermostat setting was raised to 70°F.

Fig. 21 shows the temperatures observed in the living room and north bedroom during the simulated 8 hour night period and the first 6 hours of the next day. The temperature in the living room decreased 8°F in 8 hours to a value of 60°F. At the same time a decrease of 14.7°F to a value of 57.5°F was observed in the north bedroom. The temperatures in the two rooms leveled off at the end of a 5-3/4 hour period after the thermostat setting was raised to 70°F.

12. DISCUSSIONS AND CONCLUSIONS

This investigation indicates that the heat loss of the Test Bungalow with a ceiling panel heating system agreed satisfactorily with the computed heat loss for the existing conditions of temperature and wind. The heat loss of the Test Bungalow ranged from 414 Btu to 478 Btu per degree temperature difference between indoors and outdoors. This was very close to the values observed with a baseboard convector system and with electric glass heaters before the structure was remodelled for these tests.

The reverse heat loss averaged 17.4 percent of the total panel output with 2.7 inches of ceiling insulation and 11.6 percent with 5.4 inches of ceiling insulation.

Opening the attic louvers for ventilation of the attic increased the infiltration into the living space from 30 to 35 percent, increased the heat loss from 10 to 15 percent, increased the attic temperature slightly, and decreased the reverse heat loss a small amount. These results were observed with an air movement equivalent to a 3 to 5 mph wind around the structure as produced by the blowers of the cooling units. A direct wind against one of the louvered openings would probably have decreased the attic temperature and increased the reverse heat loss.

Reliable data on the ralationship between heat emission of a ceiling panel and its average surface temperature were obtained by direct measurement of the heat input and the reverse heat loss of the panel. When maintaining a globe thermometer temperature of 70°F at the 30-inch level in the center of each room the heat emission ranged from 25 Btu/hr per sq ft for an average ceiling temperature of 93.5°F to 49 Btu/hr per sq ft for an average ceiling temperature of 112°F with a linear relationship occurring throughout this range. These values are lower than those now recommended in the Guide of the American Society of Heating and Ventilating Engineers. The corresponding values of heat emission in Fig. 11, page 560, of the 1954 Guide are about 37 Btu/hr (sq ft) at 93°F ceiling surface temperature and about 68 Btu/hr (sq ft) at 112°F ceiling surface temperature. These comparisons are made on the basis of computed values of unheated mean radiant temperature in the Test Bungalow of about 67°F for an outdoor temperature of 32°F and 63°F for an outdoor temperature of 0°F. The observed heat emission rates are only slightly higher than the computed values for radiation only shown in Fig. 9, page 557, of the 1954 Guide. The total panel output shown in the Guide is the sum of the radiation and convection components computed from two equations.

A linear relationship was also observed between the heat output of the panel and the average water temperature in the coils ranging from 25 Btu/hr (sq ft) for an average water temperature of 102°F to 65 Btu/hr (sq ft) for an average water temperature of 143°F.

The average ceiling temperatures in the individual rooms differed somewhat as a result of throttling some of the water circuits to obtain a room temperature balance. These data show that the required heat emission per square foot of ceiling area was different in different rooms, being higher in the smaller rooms with relatively large exterior wall area or with outside doors.

The temperature distribution observed in the Test Bungalow indicated that a ceiling panel system could comfortably warm an uninsulated house whose heat loss was about 61 Btu/hr (sq ft) of floor area at outdoor temperatures of -20°F. At this condition the radiation on the heads of some observers was quite noticeable. The floor surface was warmed to a temperature about 5°F above that of the air 3 inches above the floor and a globe thermometer at the 30-inch level indicated a temperature about 3 to 4°F above that of a shielded thermocouple at the same level for an outdoor temperature of 0°F.

The tests of various control systems indicated that the lag in delivery of heat to the occupied space as affected by boiler pickup and thermostat lag was of small proportion at any given outdoor temperature. The droop characteristics of the different thermostats for changing outdoor temperatures varied somewhat and this feature of the room temperature regulation requires further study.

Table 1

SUMMARY OF PANEL AREA

	Panel Area per Coil Sq. Ft.	Panel Area per Room Sq. Ft.
Living Room		
East Coil	61.25	
Center Coil	65.72	
West Coil	51.23	
		178.20
South Bedroom		
East Coil	58.22	
West Coil	57.91	
		116.13
North Bedroom		
East Coil	44.81	
West Coil	51.03	
		95.84
Kitchen		
East Coil	52.73	
West Coil	53.94	
		106.67
Bathroom	31.66	31.66
Total for House		528.50
Total not including East Coil in Living Room		467.25

anel ownward	Reverse Heat Loss to Attic, Percent of Total Panel Output	Remarks
.)		
	19.1	
	17.9	
	16.2	
	16.1	
	17.2	
	17.0	
	16.9	
	16.7	
	18.2	Warmer
	17.8	Basement
	17.4	20°F Temp. Drop
	15.5	Attic Vent.
	16.3	Attic
	17.7	Ventilated
	12.2	Double Attic
	11.3	Insulation
	10.7	
	12.1	75°F Room
	16.5	
	18.3	
	18.1	
	18.5	
	15.9	Attic Vent.
	17.1	72.5°F Room
	18.1	72.5°F Room
	17.7	75°F Room

Table 2. Summary of Results
CEILING PANEL HEATING SYSTEM IN THE TEST BUNGALOW

Test No.	Outdoor Temp.	Basement Temp.	Attic Temp.	Avg Room Temp. 2" Level	Avg Room Temp. 30" Level	Temp. Diff. 2-60"	Temp. Diff. 2-94"	Boiler Water Temperature Outlet Max.	Boiler Water Temperature Outlet Min.	Boiler Water Temperature Inlet Max.	Boiler Water Temperature Inlet Min.	Avg Ceiling Surface Temp.	Observed Heat Loss of House	Total Panel Output Downward	Unit Panel Output Downward	Reverse Heat Loss to Attic, Percent of Total Panel Output	Remarks
	°F	°F	°F	°F	°F	°F		°F	°F	°F	°F	°F	Btu/hr	Btu/hr	Btu/hr (sq. ft.)		
				Steady Heat Input, Continuous Pump Operation													
1	31.8	48.0	47.1	67.6	70.1	6.0	13.3	111.6	105.2	105.6	100.0	93.9	14350	10240	25.0	19.1	
2	31.6	47.9	46.7	66.7	69.2	6.0	13.5	106.5	105.3	101.3	100.0	93.3	15400	11280	25.8	17.9	
3	15.2	41.5	38.7	66.4	69.9	8.4	20.2	126.5	124.8	117.5	115.3	104.2	22410	17470	36.8	16.2	
4	14.8	42.0	37.8	66.3	69.6	8.1	19.8	126.0	125.0	117.3	116.4	106.1	22430	17500	42.8	16.1	
5	- 0.1	38.2	29.5	66.0	70.3	10.4	26.8	133.1	132.0	123.2	122.5	112.3	29500	22920	49.1	17.2	
6	0.1	37.8	29.0	66.1	70.0	9.8	26.4	132.2	132.0	122.5	122.1	111.4	29420	23030	49.3	17.0	
7	-20.4	35.1	19.7	66.3	71.2	12.5	33.8	154.0	152.0	142.0	140.6	124.2	37610	29940	64.1	16.9	
8	-20.4	34.9	19.8	66.3	71.4	12.7	33.8	154.0	152.6	141.1	140.3	123.5	37520	30030	64.3	16.7	
9	- 0.5	49.5	29.3	66.6	70.0	8.7	23.3	127.8	126.3	118.5	118.0	108.0	26160	20100	43.0	18.2	Warmer
10	- 0.3	59.2	30.0	67.5	70.9	8.5	22.9	129.5	126.3	120.0	117.5	108.0	26580	20575	44.5	17.8	Basement
11	- 0.1	37.8	29.7	66.2	70.6	10.7	27.8	149.1	147.5	126.0	125.0	112.8	29990	23320	49.9	17.4	20°F Temp.Drop
12	0.4	38.2	37.3	65.7	70.4	11.6	30.6	149.0	145.0	137.0	134.4	119.4	33950	26950	57.7	15.5	Attic Vent.
13	14.8	41.9	40.8	66.2	69.5	8.4	22.8	126.7	125.0	118.0	117.0	106.9	25540	20000	42.8	16.3	Attic
14	31.8	48.0	47.7	67.2	69.6	6.0	15.5	106.0	104.2	100.1	99.2	93.4	16680	12380	26.5	17.7	Ventilated
15	32.0	48.1	42.7	67.4	70.2	6.8	16.6	108.1	107.1	103.0	101.7	94.8	15530	12140	26.0	12.2	Double Attic
16	14.9	42.4	33.1	65.9	69.8	9.4	23.5	127.8	123.2	119.2	116.1	105.3	22630	18530	39.7	11.3	Insulation
17	0.0	38.1	26.0	64.8	69.5	11.2	28.9	139.3	138.8	130.1	129.2	114.4	28380	23760	50.9	10.7	
18	32.1	48.4	45.1	72.1	75.1	7.4	18.3	119.1	113.9	113.1	108.2	102.1	17190	13620	29.2	12.1	75°F Room
			Three-Wire Room Thermostat on Heaters, Continuous Pump Operation														
19	-20.0	33.9	21.2	65.7	70.8	12.4	33.0	160.2	124.9	147.2	123.2	123.5	37360	29880	64.0	16.5	
20	- 0.4	37.9	29.5	65.5	69.9	10.6	28.0	145.0	123.2	140.2	120.5	113.2	28300	21610	46.3	18.3	
21	15.2	41.9	38.2	66.6	70.0	8.4	21.3	125.8	112.9	125.5	109.1	102.0	22090	16640	35.6	18.1	
22	32.0	48.7	44.8	67.6	70.1	6.4	16.2	112.0	98.0	102.8	96.0	92.9	15780	11600	24.8	18.5	
23	- 0.4	37.8	34.9	65.3	69.5	10.9	30.1	149.5	134.5	137.0	128.0	117.6	32680	25940	55.5	15.9	Attic Vent.
24	0.0	37.8	32.5	67.9	72.5	11.2	28.9	149.0	129.0	136.9	129.0	117.7	31440	24230	51.9	17.1	72.5°F Room
25	32.1	47.9	47.4	69.6	72.5	6.9	16.5	119.5	101.7	110.2	99.0	95.5	17440	12810	27.4	18.1	72.5°F Room
26	31.9	47.9	49.7	72.3	75.3	7.3	18.2	123.0	110.0	115.9	104.3	101.5	19410	14580	31.2	17.7	75°F Room

Panel Downward ir ft.)	Reverse Heat Loss to Attic, Percent of Total Panel Output	Remarks
	17.6	
	17.7	
	18.1	
	19.3	
	17.7	
	17.3	
	18.5	
	16.2	
	17.1	
	17.9	
	17.3	
	16.0	
	16.2	
	17.4	
	19.3	
	15.9	75°F Room
	16.8	75°F Room
	18.2	

Table 2. Summary of Results

CEILING PANEL HEATING SYSTEM IN THE TEST BUNGALOW

Test No.	Outdoor Temp.	Basement Temp.	Attic Temp.	Avg Room Temp. 2" Level	Avg Room Temp. 30" Level	Temp. Diff. 2-60"	Temp. Diff. 2-94"	Boiler Water Temperature Outlet Max.	Outlet Min.	Inlet Max.	Inlet Min.	Avg Ceiling Surface Temp.	Observed Heat Loss of House	Total Panel Output Downward	Unit Panel Output Downward	Reverse Heat Loss to Attic, Percent of Total Panel Output	Remarks
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	Btu/hr	Btu/hr	Btu/hr (sq. ft.)		
	Two-Wire Room Thermostat on Heaters, Continuous Pump Operation																
27	14.7	41.9	38.2	66.7	69.9	8.3	21.2	133.0	105.6	118.2	104.8	103.8	22920	17490	37.4	17.6	
28	31.9	47.9	46.8	67.5	69.9	6.0	14.6	125.1	92.0	110.1	91.0	91.2	16290	11900	25.5	17.7	
	Two-Wire Room Thermostat on Heaters, Aquastat on Pump																
29	32.0	48.0	48.5	68.1	70.7	6.7	15.8	113.0	97.5	102.0	96.0	93.9	16450	12130	26.0	18.1	
30	32.2	48.5	47.6	68.8	71.5	6.4	15.7	180.0	123.0	110.5	88.0	93.8	15390	10910	23.4	19.3	
	Three-Wire Room Thermostat Controlling Both Heaters and Pump																
31	0.1	38.1	29.9	65.9	70.3	10.7	27.6	145.0	137.5	129.2	119.1	112.7	29010	22330	47.8	17.7	
32	15.0	41.7	38.8	66.8	70.5	9.0	22.9	135.0	129.9	121.0	113.0	106.3	24330	18720	40.1	17.3	
33	32.0	48.0	47.0	68.0	70.7	6.5	16.2	118.6	112.4	106.0	97.2	94.4	16400	12030	25.8	18.5	
	Aquastat on Heaters, Room Thermostat on Pump																
34	-0.1	37.8	32.2	66.1	70.7	11.3	29.2	154.0	143.0	133.5	122.4	116.4	31470	25080	53.7	16.2	
35	14.7	41.9	39.7	67.7	71.5	9.4	24.2	163.4	129.0	127.0	119.8	107.9	24700	19020	40.7	17.1	
36	31.5	47.9	47.0	68.8	71.9	7.4	17.6	155.6	116.8	115.4	102.0	97.6	16990	12640	27.1	17.9	
37	49.8	53.5	58.3	70.7	72.5	4.5	11.0	156.4	123.2	100.4	86.1	86.4	10380	7410	15.9	17.3	
	Three-Wire Room Thermostat on Pump, Outdoor Reset Control on Heaters																
38	-0.8	38.1	34.5	64.9	69.4	11.5	29.5	152.8	137.2	135.3	128.7	116.5	32010	25490	54.6	16.0	
39	0.0	37.9	33.8	65.4	69.8	11.0	28.7	146.9	133.2	133.2	130.0	115.8	31510	24970	53.4	16.2	
40	15.1	42.7	39.8	66.4	70.1	9.2	23.2	136.2	116.6	119.8	112.0	105.7	23830	18160	38.9	17.4	
41	32.0	48.1	47.5	67.8	70.4	6.5	15.9	119.2	103.9	104.5	97.7	94.8	15750	11290	24.2	19.3	
42	0.0	38.0	35.9	69.5	74.6	12.4	32.3	167.0	152.4	146.0	132.1	124.8	35260	28290	60.6	15.9	75°F Room
43	15.1	42.3	41.9	70.9	75.3	10.5	24.5	148.6	132.0	134.2	124.3	115.7	27870	21890	46.9	16.8	75°F Room
	Hydrogen-Filled Thermostat on Pump, Outdoor Reset Control on Heaters																
44	32.6	48.5	48.1	67.8	70.6	6.7	16.7	118.5	105.0	104.0	102.0	95.6	16540	12130	26.0	18.2	

l	Panel
Weighted Average	Area Heated
°F	sq.ft.
93.9	409.4
93.3	435.6
104.2	467.3
106.8	409.4
112.3	467.3
111.4	467.3
124.2	467.3
123.5	467.3
108.0	467.3
108.0	467.3
112.8	467.3
119.4	467.3
106.9	467.3
93.4	467.3
94.8	467.3
105.3	467.3
114.4	467.3
102.1	467.3

Table 3. Temperatures on Heated Panel

CEILING SURFACE TEMPERATURES

Test No.	Outdoor Temp.	Living Room Center Panel	Living Room West Panel	Living Room Weighted Average	South Bedroom East Panel	South Bedroom West Panel	South Bedroom Weighted Average	North Bedroom East Panel	North Bedroom West Panel	North Bedroom Weighted Average
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
1	31.8	96.7	88.5	93.1	93.6	78.6*	93.6	98.2	98.3	98.3
2	31.6	95.4	89.2	92.7	93.0	87.7	90.4	96.1	96.7	96.4
3	15.2	108.5	95.8	102.9	105.3	87.4	96.4	110.0	110.2	110.1
4	14.8	108.5	94.6	102.4	104.9	79.4*	104.9	110.4	110.9	110.7
5	- 0.1	113.4	114.8	114.0	110.7	107.0	108.9	115.1	115.3	115.2
6	0.1	109.3	114.4	111.5	109.9	106.6	108.3	114.9	115.0	115.0
7	-20.4	121.7	112.9	117.8	115.9	122.2	119.1	129.4	129.9	129.7
8	-20.4	120.1	112.0	116.6	114.6	120.4	117.5	129.7	130.1	129.9
9	- 0.5	106.2	107.5	106.8	102.0	104.9	103.4	110.8	110.6	110.7
10	- 0.3	104.7	108.1	106.2	101.4	104.5	102.9	111.3	111.6	111.5
11	- 0.1	100.5	109.9	104.6	96.3	106.8	101.5	123.1	123.7	123.4
12	0.4	114.0	117.4	115.5	109.6	115.7	112.6	124.2	124.8	124.5
13	14.8	105.4	106.2	105.8	100.3	102.1	101.2	110.2	110.5	110.4
14	31.8	92.6	93.5	93.0	89.3	89.9	89.6	95.5	95.7	95.6
15	32.0	93.9	92.9	93.5	90.4	91.8	91.1	96.3	96.9	96.6
16	14.9	104.0	102.5	103.3	98.8	101.0	99.9	107.7	108.4	108.1
17	0.0	112.7	110.7	111.8	105.9	109.0	107.4	117.6	118.3	118.0
18	32.1	101.0	99.6	100.4	97.1	98.8	97.9	103.9	104.4	104.2

Test No.	Kitchen East Panel	Kitchen West Panel	Kitchen Weighted Average	Bath	Total Arithmatic Average	Total Weighted Average	Panel Area Heated
	°F	°F	°F	°F	°F	°F	sq.ft.
1	96.7	92.6	94.6	81.3	93.2	93.9	409.4
2	95.8	92.8	94.3	73.8*	93.3	93.3	435.6
3	108.3	102.7	105.5	98.7	103.0	104.2	467.3
4	108.2	102.5	105.3	94.0	104.3	106.8	409.4
5	108.1	113.0	110.6	115.8	112.6	112.3	467.3
6	107.7	112.8	110.3	115.0	111.7	111.4	467.3
7	129.9	129.3	129.6	131.0	124.7	124.2	467.3
8	130.0	129.5	129.7	130.6	124.1	123.5	467.3
9	111.2	110.9	111.0	110.7	108.3	108.0	467.3
10	111.8	111.4	111.6	111.2	108.4	108.0	467.3
11	122.2	121.9	122.0	122.1	114.1	112.8	467.3
12	124.8	124.5	124.6	125.1	120.0	119.4	467.3
13	110.4	110.2	110.3	109.9	107.2	106.9	467.3
14	95.6	95.4	95.5	95.7	93.7	93.4	467.3
15	97.7	97.6	97.6	98.0	95.1	94.8	467.3
16	109.6	109.6	109.6	109.7	105.7	105.3	467.3
17	119.9	119.9	119.9	119.6	114.8	114.4	467.3
18	105.4	105.5	105.5	105.5	102.4	102.1	467.3

* These panels unheated during this test.

TABLE 4 - Test No. 2
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation)
Outdoor Temp. 31.6°F Avg Panel Output, 25.8 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.2	67.3	65.6	66.8	66.5	66.7	1.7
30	69.5	69.1	68.0	69.5	69.8	69.2	1.8
60	73.0	72.1	71.2	73.4	73.9	72.7	2.7
78	76.1	74.5	73.4	76.3	76.9	75.4	3.5
94	82.6	77.3	74.7	83.6	82.9	80.2	8.9
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	1.6	1.6	1.3	1.6	2.2	1.7	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	5.8	4.8	5.6	6.6	7.4	6.0	
2-94	15.4	10.0	9.1	16.8	16.4	13.5	

Average Basement Temperature	47.9°F
Average Attic Temperature	46.7°F
Average Ceiling Temperature	93.3°F
Average 30" Level Air Temperature	68.4°F
Average 30" Level Temp. 8-in. Globe	70.2°F

Table 5 - Test No. 4
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation)
Outdoor Temp. 14.8°F   Avg Panel Output, 42.8 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.0	66.7	66.4	67.0	64.5	66.3	2.5
30	70.0	69.4	69.1	70.5	69.1	69.6	1.4
60	74.8	73.4	74.3	75.8	73.8	74.4	2.4
78	79.2	76.4	80.4	80.4	76.5	78.6	4.0
94	89.3	80.2	87.3	91.9	82.0	86.1	11.7
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	2.0	2.4	1.6	2.0	1.2	1.8	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	7.8	6.7	7.9	8.8	9.3	8.1	
2-94	22.3	13.5	20.9	24.9	17.5	19.8	

Average Basement Temperature - 42.0°F
Average Attic Temperature - 37.8°F
Average Ceiling Temperature - 106.1°F
Average 30" Level Temp., 8-in. Globe 70.4°F
Average 30" Level Air Temp. 67.9°F

Table 6 - Test No. 6
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation)
Outdoor Temp. 0.1°F Avg Panel Output, 49.3 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature: Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room	Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
Inches	°F	°F	°F	°F	°F	°F	°F
2	65.9	66.8	66.9	65.6	65.4	66.1	1.5
30	69.9	70.0	69.7	70.3	70.2	70.0	0.6
60	75.4	75.0	75.9	76.4	76.8	75.9	1.8
78	80.9	81.5	85.7	81.6	81.8	82.3	4.8
94	92.6	85.9	96.9	95.2	92.0	92.5	11.0
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	2.3	3.1	1.5	2.5	4.1	2.7	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	9.5	8.2	9.0	10.8	11.4	9.8	
2-94	26.7	19.1	30.0	29.6	26.6	26.4	

Average Basement Temperature - 37.8°F
Average Attic Temperature 29.0°F
Average Ceiling Temperature - 111.4°F
Average 30" Level Temp. 8-in. Globe 70.7°F
Average 30" Level Air Temp - 67.5°F

TABLE 7 - Test No. 8
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation)
Outdoor Temp. -20.4°F Avg Panel Output, 64.3 Btu/hr (sq.ft)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.9	64.8	68.6	65.8	64.3	66.3	4.3
30	72.2	69.2	74.2	71.2	70.4	71.4	5.0
60	79.4	74.0	83.3	78.9	79.3	79.0	9.3
78	86.1	79.8	94.0	86.3	85.4	86.3	14.2
94	103.7	85.7	107.5	103.2	97.7	99.6	21.8
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	2.8	3.8	2.2	3.2	6.5	3.7	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	11.5	9.2	14.7	13.1	15.0	12.7	
2-94	35.8	20.9	38.9	37.4	33.4	33.3	

Average Basement Temperature	34.9°F
Average Attic Temperature	19.8°F
Average Ceiling Temperature	123.5°F
Average 30" Level Temp. 8-in. Globe	72.3°F
Average 30" Level Air Temp	68.8°F

Table 8 - Test No. 14
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation, Attic Ventilated)
Outdoor Temp. 31.8°F Avg Panel Output, 26.5 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.5	67.2	67.9	66.8	66.8	67.2	1.1
30	69.6	69.2	69.8	69.5	69.7	69.6	0.6
60	73.3	72.3	74.0	73.3	73.5	73.3	1.7
78	76.6	74.9	79.5	76.1	76.3	76.7	4.6
94	84.0	78.4	86.3	83.4	81.6	82.7	7.9
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	1.8	1.8	3.2	1.5	2.7	2.2	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	5.8	5.1	6.1	6.5	6.7	6.0	
2-94	16.5	11.2	18.4	16.6	14.8	15.5	

Average Basement Temperature	48.0°F
Average Attic Temperature	47.7°F
Average 30" Level Temp, 8-in. Globe	70.3°F
Average 30" Level Air Temp	68.6°F
Average Ceiling Temperature	93.4°F

Table 9 - Test No. 13
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation, Attic Ventilated)
Outdoor Temp. 14.8°F Avg Panel Output, 42.8 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	66.7	66.1	66.8	65.8	65.7	66.2	1.1
30	69.7	69.1	69.2	69.8	69.6	69.5	0.7
60	75.0	73.5	75.0	75.0	74.8	74.7	1.5
78	80.0	77.2	82.9	79.5	78.8	79.7	5.7
94	91.5	82.6	93.0	91.0	86.9	89.0	10.4
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	2.1	2.6	2.1	2.3	1.8	2.2	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	8.3	7.4	8.2	9.2	9.1	8.4	
2-94	24.8	16.5	26.2	25.2	21.2	22.8	

Average Basement Temperature	41.9°F
Average Attic Temperature	40.8°F
Average Ceiling Temperature	106.9°F
Average 30" Level Temp, 8-in. Globe	70.4°F
Average 30" Level Air Temp.	67.4°F

Table 10 - Test No. 12
Temperature Distribution in Test Bungalow
(Single Thickness Ceiling Insulation, Attic Ventilated)
Outdoor Temp., 0.4°F Avg Panel Output, 57.7 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature: Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room	Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.1	65.0	66.5	65.1	65.0	65.7	2.1
30	70.9	69.6	70.0	71.1	70.5	70.4	1.5
60	78.1	75.1	77.9	78.3	77.5	77.4	3.2
78	84.8	79.7	87.9	83.9	82.5	83.8	8.2
94	100.3	86.0	102.0	99.4	93.8	96.3	16.0
	B. MAXIMUM HORIZONTAL TEMPERATURE DIFFERENCE						
30	2.6	3.1	2.2	2.4	2.5	25.6	
	C. VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE						
2-60	11.0	10.1	11.4	13.2	12.5	11.6	
2-94	33.2	21.0	35.5	34.3	28.8	30.6	

Average Basement Temperature	38.2°F
Average Attic Temperature	37.3°F
Average Ceiling Temperature	119.4°F
Average 30" Level Temp, 8-in Globe	71.3°F
Average 30" Level Air Temp.	66.8°F

Table 11 - Test No. 15
Temperature Distribution in Test Bungalow
(Double Thickness Ceiling Insulation)
Outdoor Temp., 32.0°F Avg Panel Output, 26.0 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.9	67.2	68.3	66.7	66.7	67.4	1.6
30	70.3	69.6	70.4	70.3	70.3	70.2	0.8
60	74.3	72.9	75.1	74.2	74.3	74.2	2.2
78	78.0	75.4	81.9	77.0	77.5	78.0	6.5
94	85.7	78.6	88.6	84.4	82.3	83.9	10.0
	B. Maximum Horizontal Temperature Difference						
30	1.6	1.6	1.2	1.5	2.0	1.6	
	C. Vertical Temperature Difference, Room Average						
2-60	6.4	5.7	6.8	7.5	7.6	6.8	
2-94	17.8	11.4	20.3	17.7	15.6	16.6	

Average Basement Temperature	48.1°F
Average Attic Temperature	42.7°F
Average Ceiling Temperature	94.8°F
Average 30" Level Temp., 8-in. Globe	70.6°F
Average 30" Level Air Temp.	69.0°F

Table 12 - Test No. 16
Temperature Distribution in Test Bungalow
(Double Thickness Ceiling Insulation)
Outdoor Temp., 14.9°F Avg Panel Output, 39.7 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	66.9	65.8	66.8	65.0	64.9	65.9	2.0
30	70.2	69.2	69.8	69.8	69.8	69.8	1.0
60	75.6	73.7	76.1	75.5	75.4	75.3	2.4
78	80.9	77.4	84.7	79.7	79.3	80.4	7.3
94	92.6	82.1	94.6	90.4	87.0	89.3	12.5
	B. Maximum Horizontal Temperature Difference						
30	2.1	2.4	1.8	2.1	2.9	2.3	
	C. Vertical Temperature Difference, Room Average						
2-60	8.7	7.9	9.3	10.5	10.5	9.4	
2-94	25.7	16.3	27.8	25.4	22.1	23.5	

Average Basement Temperature	42.4°F
Average Attic Temperature	33.1°F
Average Ceiling Temperature	105.3°F
Average 30" Level Temp., 8-in. Globe	70.7°F
Average 30" Level Air Temp.	67.8°F

Table 13 - Test No. 17
Temperature Distribution in Test Bungalow
(Double Thickness Ceiling Insulation)
Outdoor Temp., 0.0°F Avg Panel Output, 50.9 Btu/hr (sq.ft.)

Height Above Floor	A. Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	66.2	64.7	65.8	64.0	63.5	64.8	2.7
30	70.2	68.9	69.2	69.7	69.3	69.5	1.3
60	76.8	74.2	76.8	76.5	76.1	76.1	2.6
78	83.4	78.7	87.2	81.5	80.6	82.3	8.5
94	98.1	84.6	99.8	95.4	90.7	93.7	15.2
	B. Maximum Horizontal Temperature Difference						
30	2.6	3.0	1.9	2.9	3.3	2.7	
	C. Vertical Temperature Difference, Room Average						
2-60	10.6	9.5	11.0	12.5	12.6	11.2	
2-94	31.9	19.9	34.0	31.4	27.2	28.9	

Average Basement Temperature	38.1°F
Average Attic Temperature	26.0°F
Average Ceiling Temperature	114.4°F
Average 30" Level Temp., 8-in. Globe	70.3°F
Average 30" Level Air Temp.	66.5°F

Fig. 1

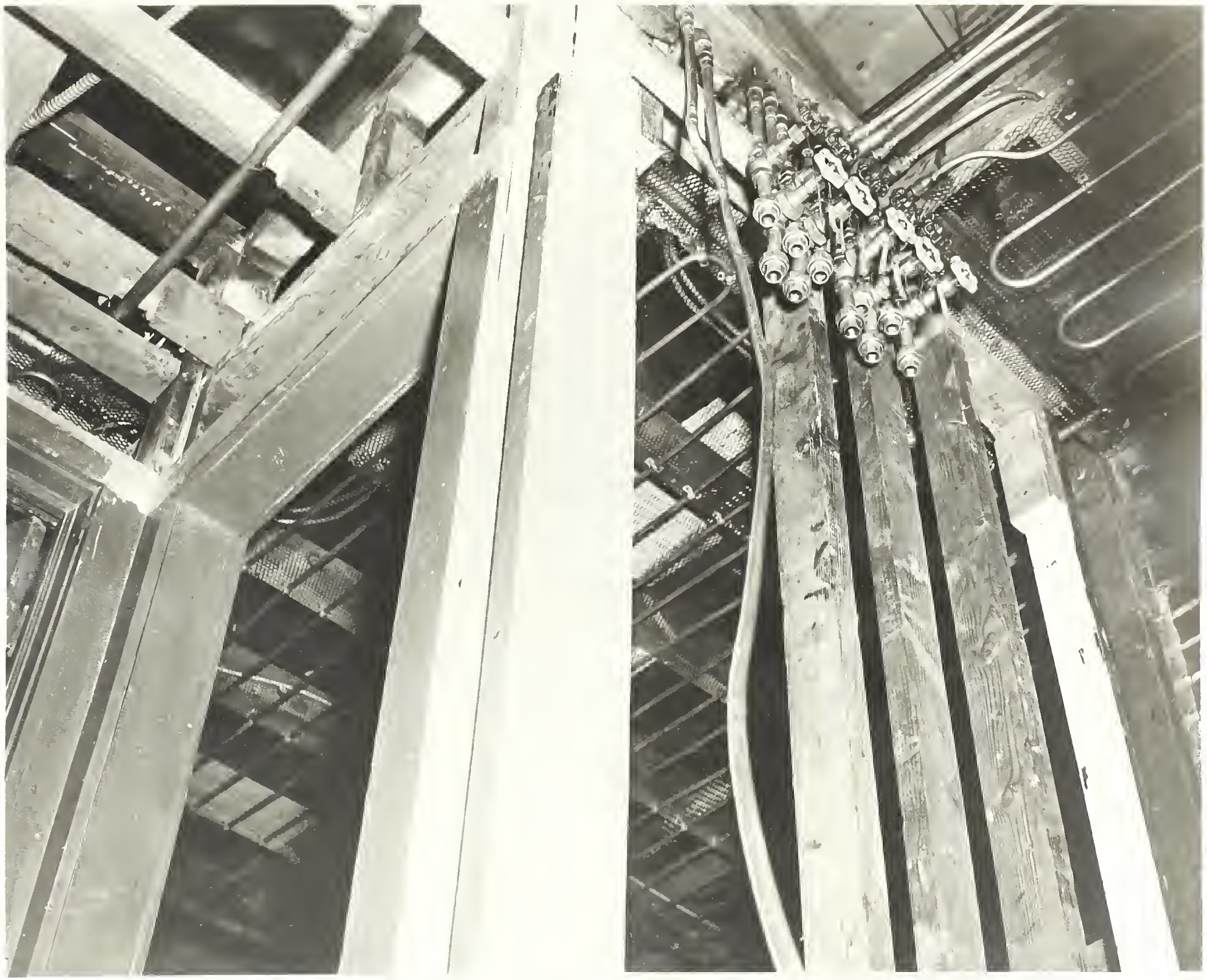


Fig. 2

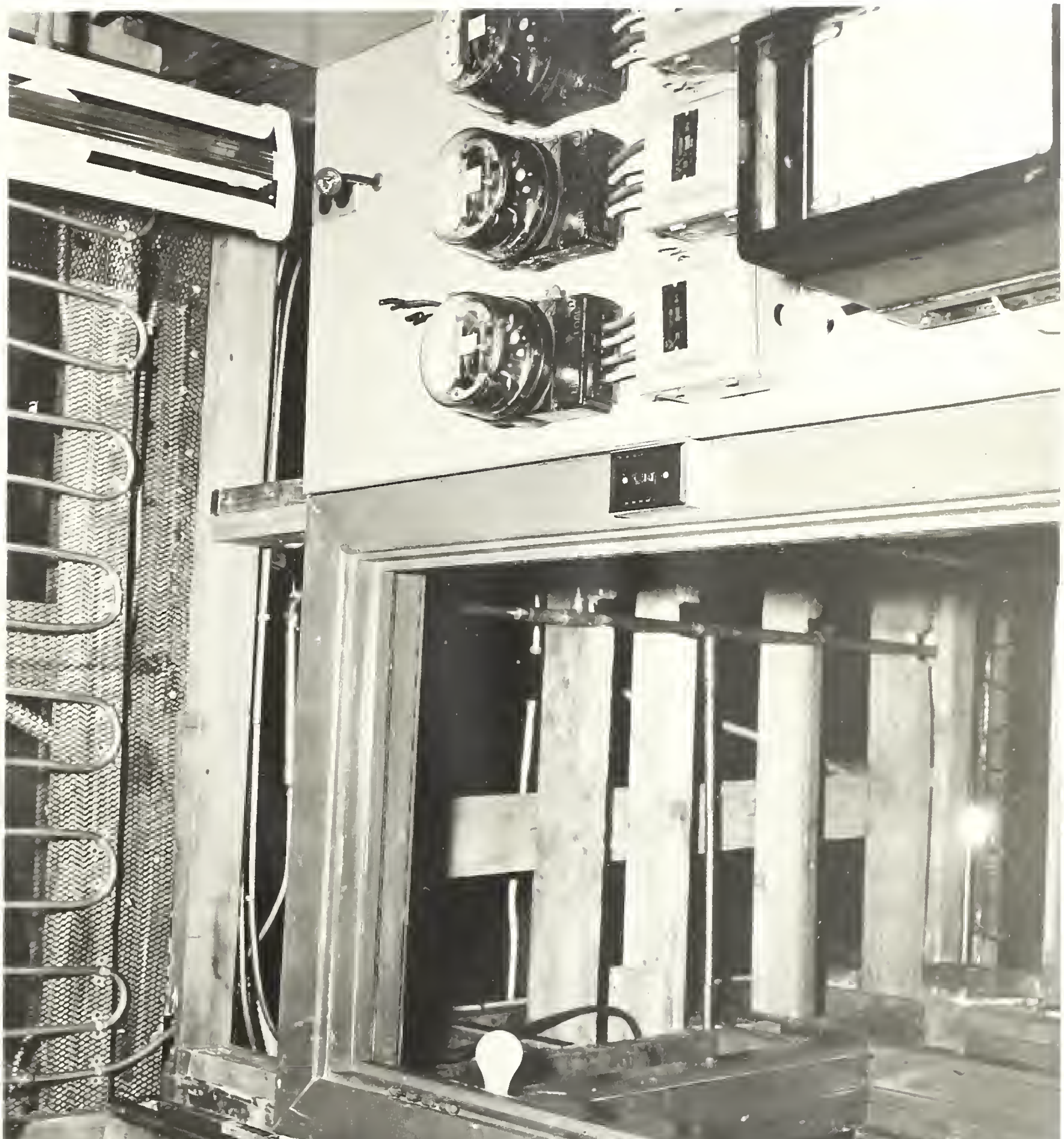


Fig. 3

Fig. 4

Fig. 5

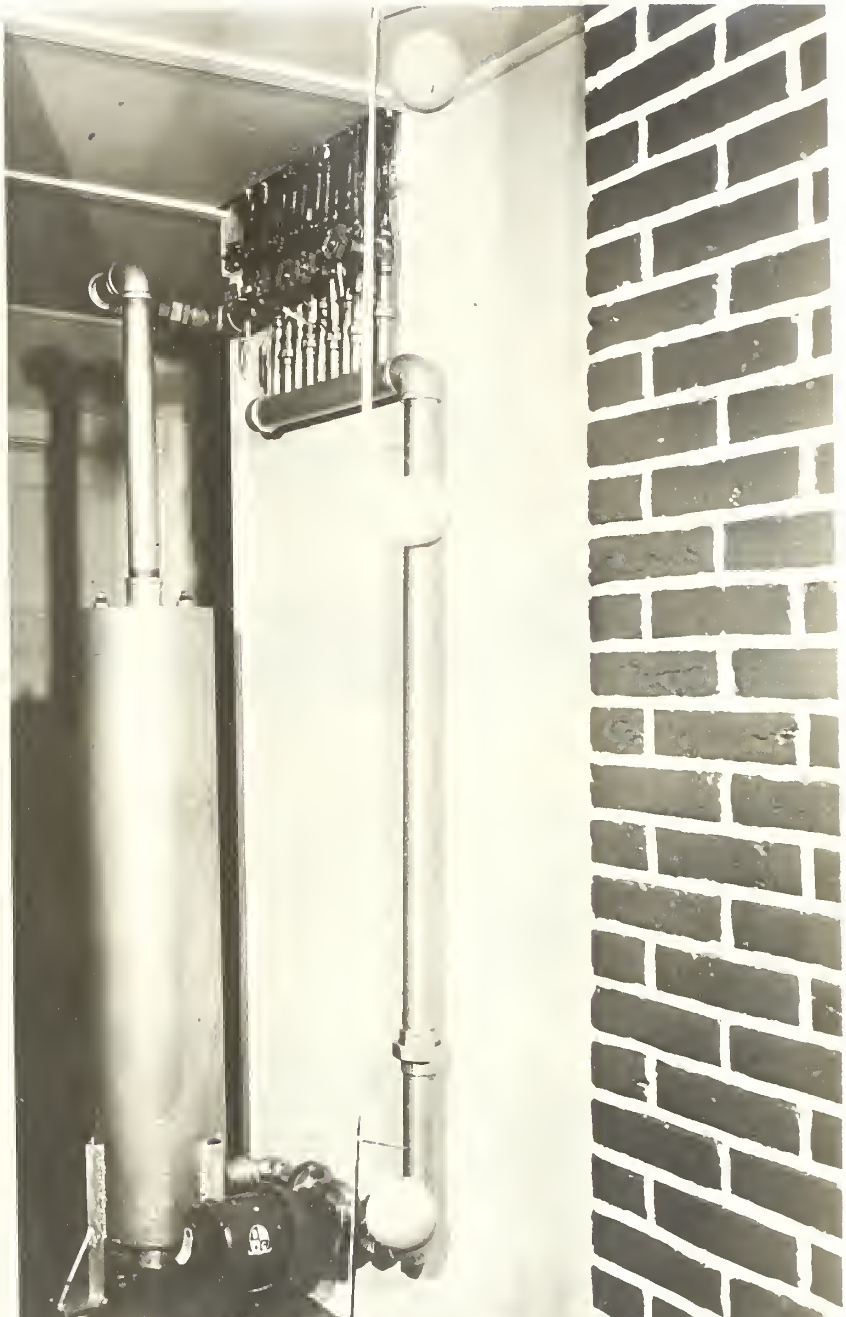
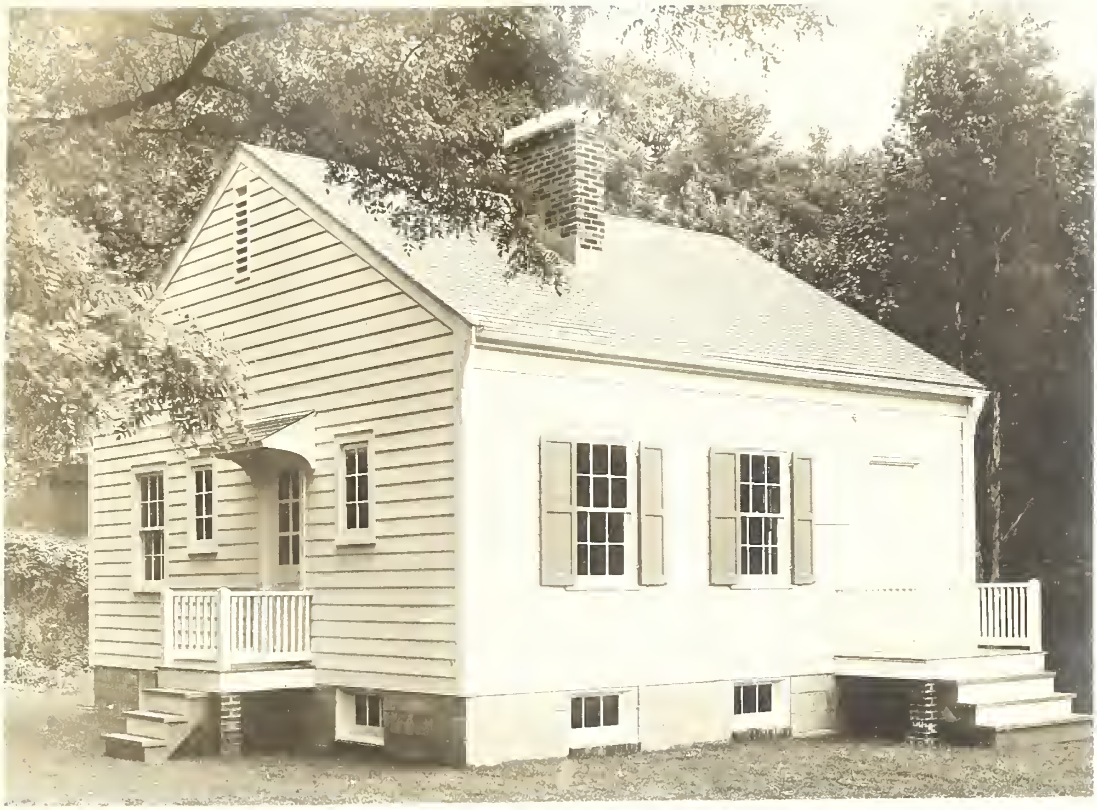


Fig. 6



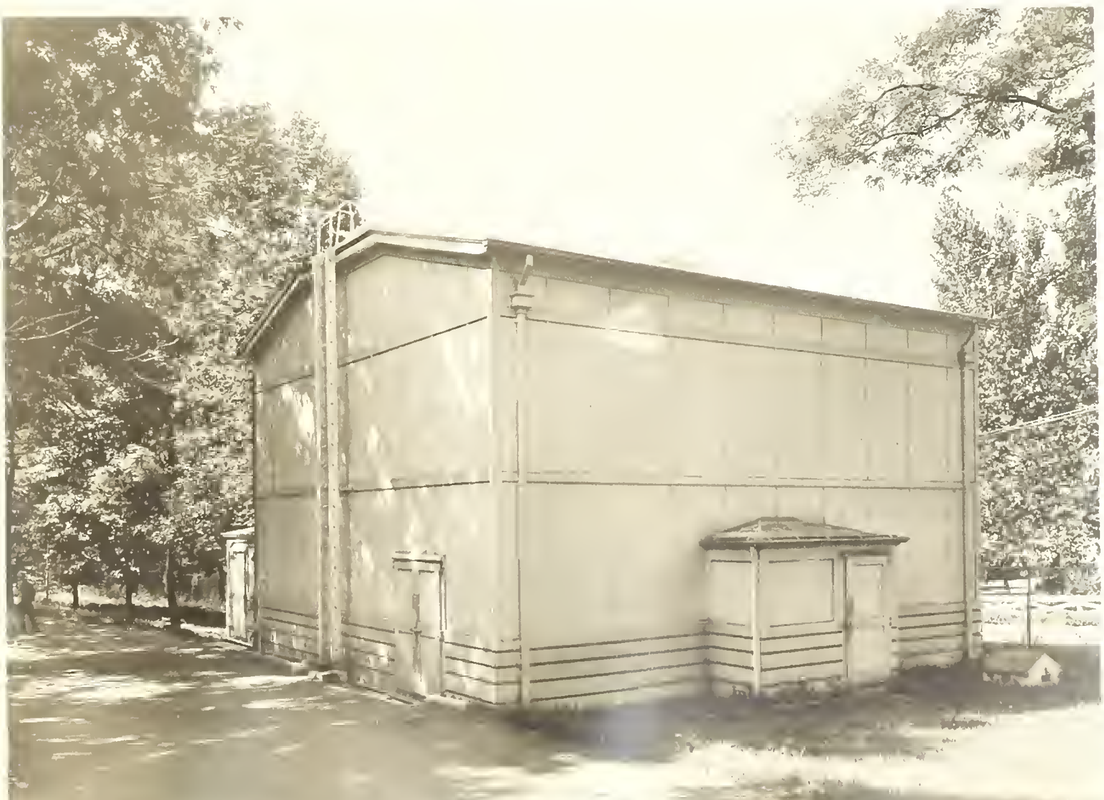


Fig. 7

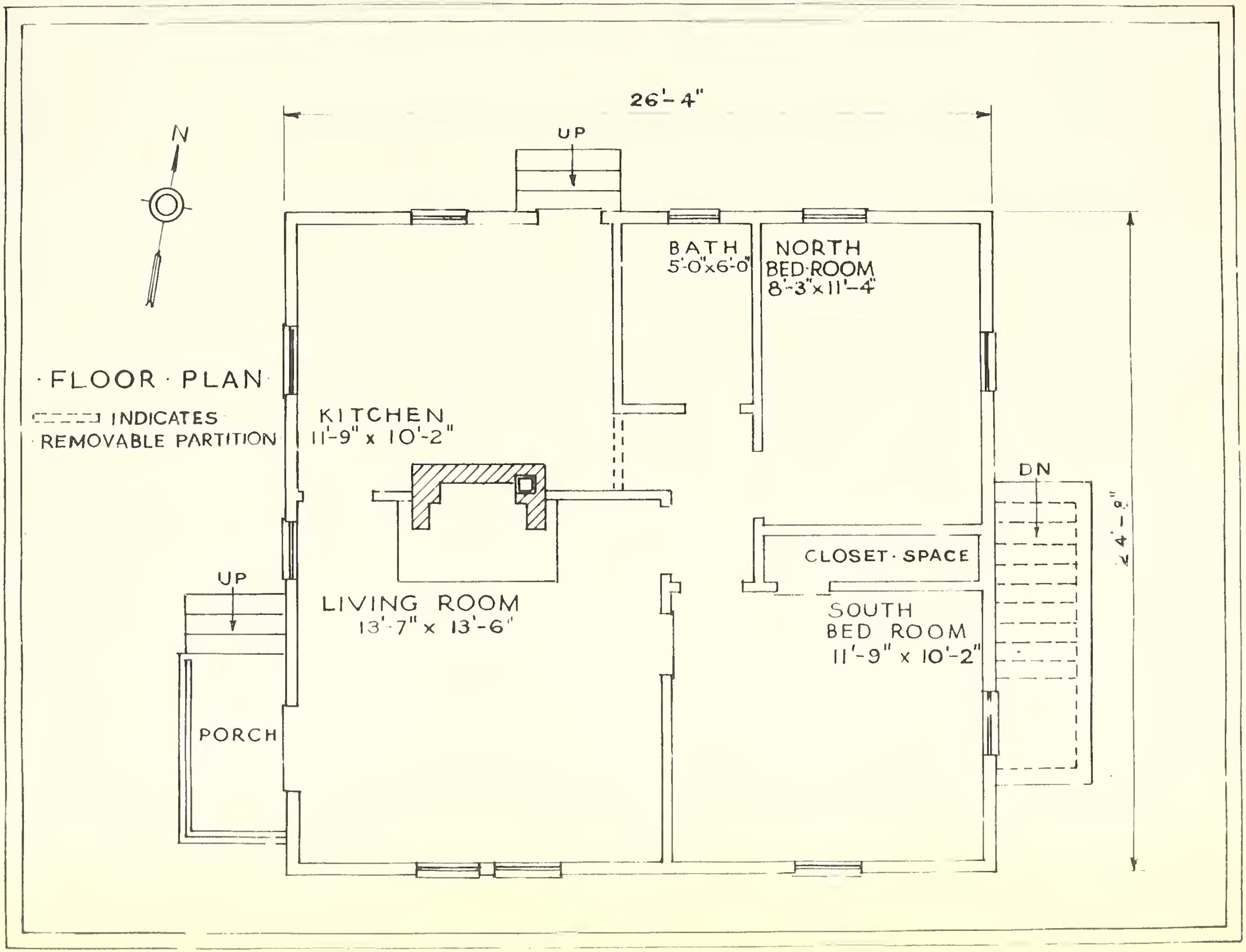
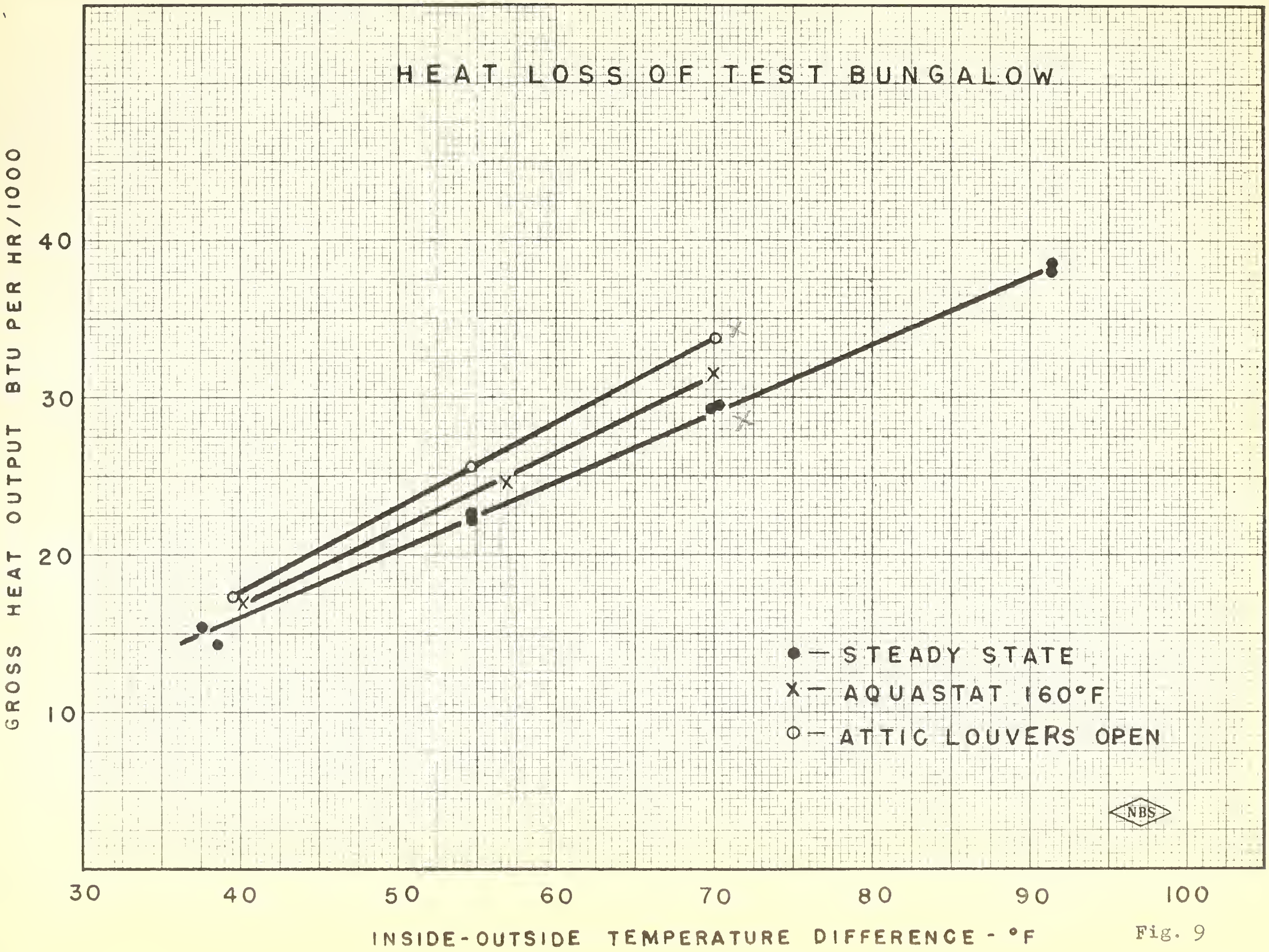
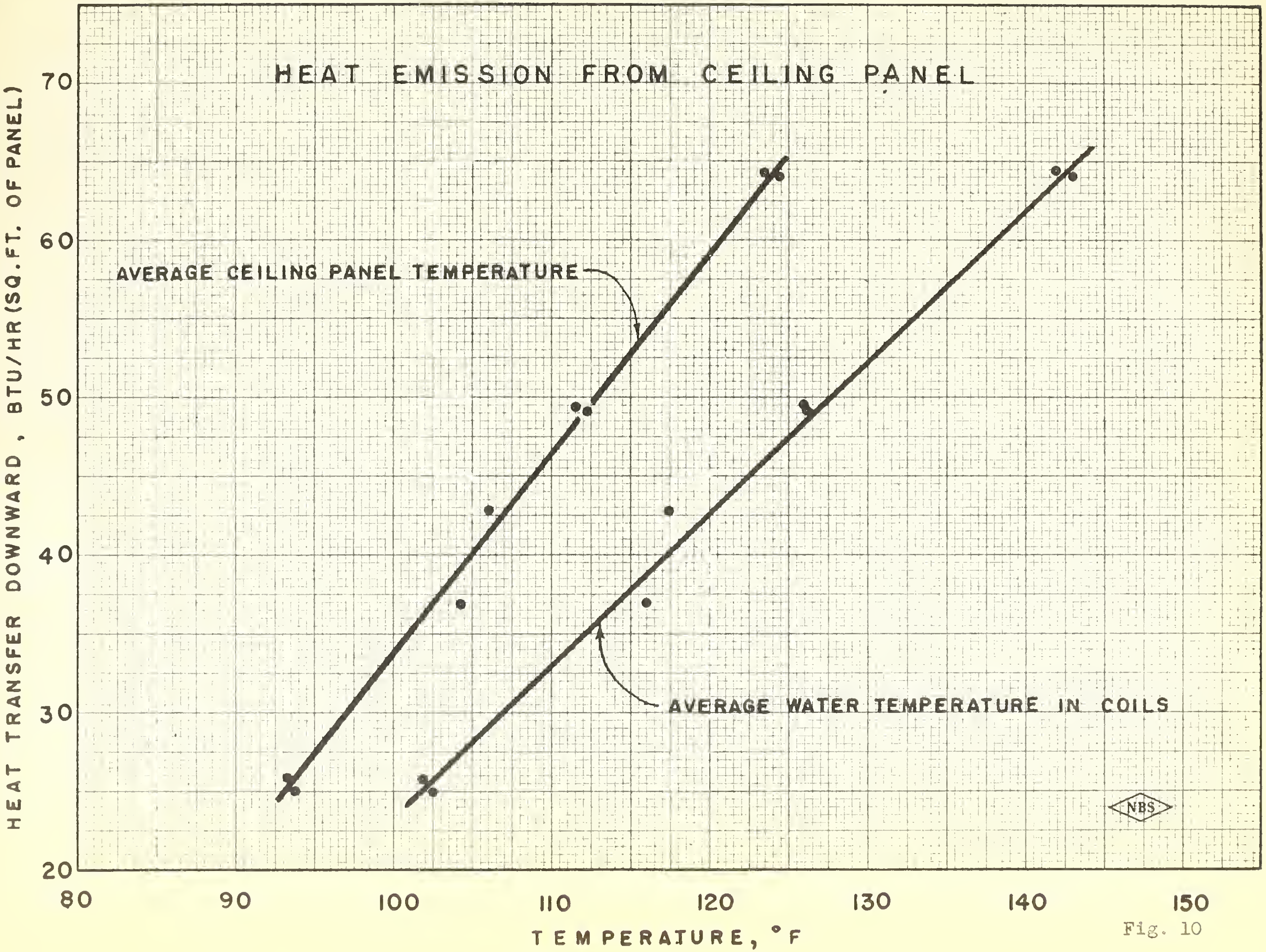

26'-4"
24'-8"
UP
UP
DN
BATH
5'-0"x6'-0"
NORTH
BED·ROOM
8'-3"x11'-4"
·FLOOR · PLAN·
INDICATES
REMOVABLE PARTITION
KITCHEN
11'-9" x 10'-2"
LIVING ROOM
13'-7" x 13'-6"
CLOSET · SPACE
SOUTH
BED ROOM
11'-9" x 10'-2"
PORCH
N

Fig. 8



HEAT LOSS OF TEST BUNGALOW
GROSS HEAT OUTPUT BTU PER HR/1000
10
20
30
40
30
40
50
60
70
80
90
100
INSIDE-OUTSIDE TEMPERATURE DIFFERENCE - °F
● — STEADY STATE
X — AQUASTAT 160°F
O — ATTIC LOUVERS OPEN

Fig. 9


HEAT EMISSION FROM CEILING PANEL
AVERAGE CEILING PANEL TEMPERATURE
AVERAGE WATER TEMPERATURE IN COILS
HEAT TRANSFER DOWNWARD, BTU/HR(SQ.FT. OF PANEL)
TEMPERATURE, °F
20
30
40
50
60
70
80
90
100
110
120
130
140
150
NBS
Fig. 10

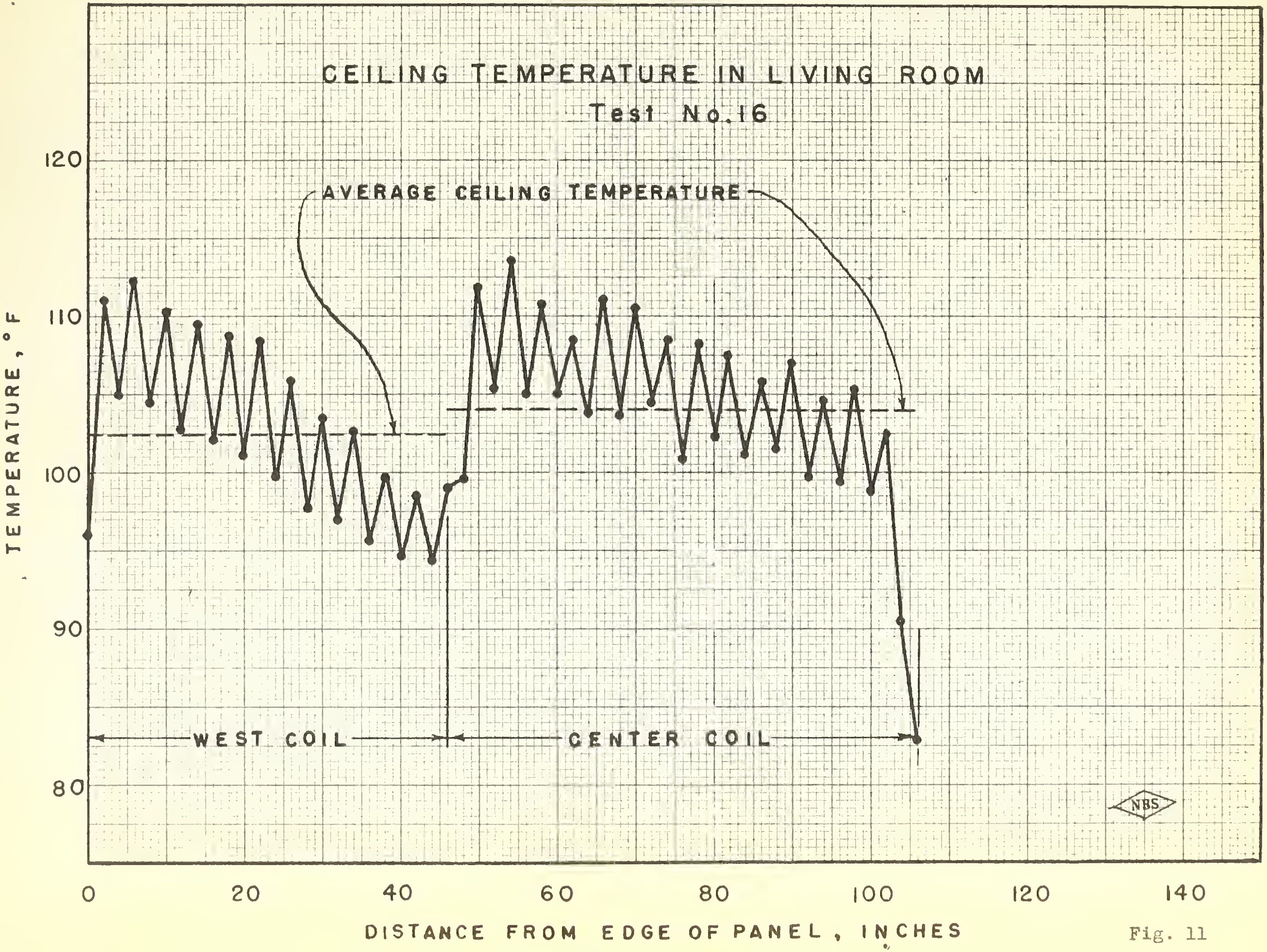

CEILING TEMPERATURE IN LIVING ROOM
Test No. 16
AVERAGE CEILING TEMPERATURE
WEST COIL
CENTER COIL
NBS
TEMPERATURE, °F
120
110
100
90
80
0
20
40
60
80
100
120
140
DISTANCE FROM EDGE OF PANEL, INCHES

Fig. 11

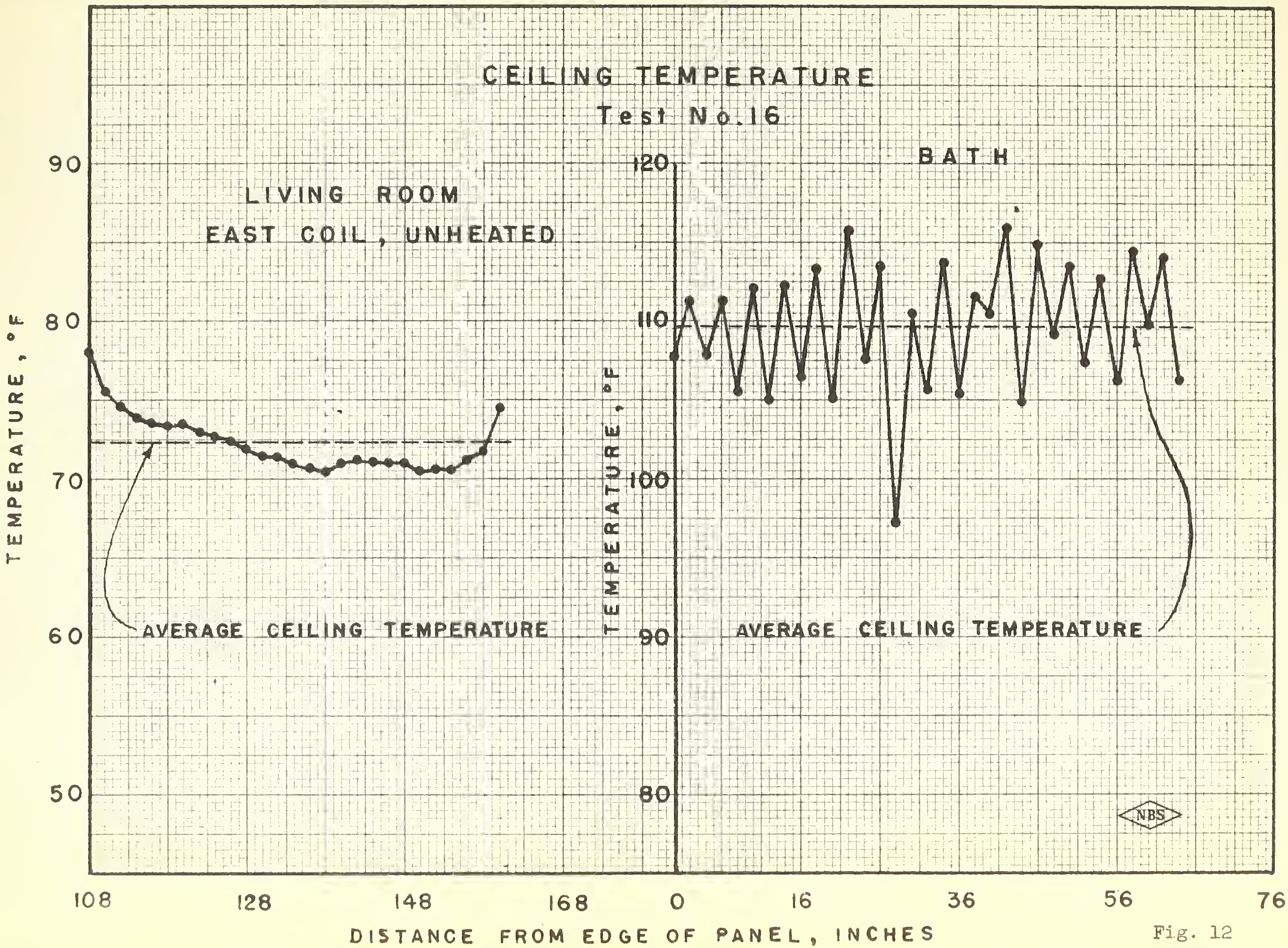

CEILING TEMPERATURE
Test No.16
LIVING ROOM
EAST COIL, UNHEATED
BATH
AVERAGE CEILING TEMPERATURE
AVERAGE CEILING TEMPERATURE
TEMPERATURE, °F
TEMPERATURE, °F
90
80
70
60
50
120
110
100
90
80
108
128
148
168
0
16
36
56
76
DISTANCE FROM EDGE OF PANEL, INCHES

Fig. 12

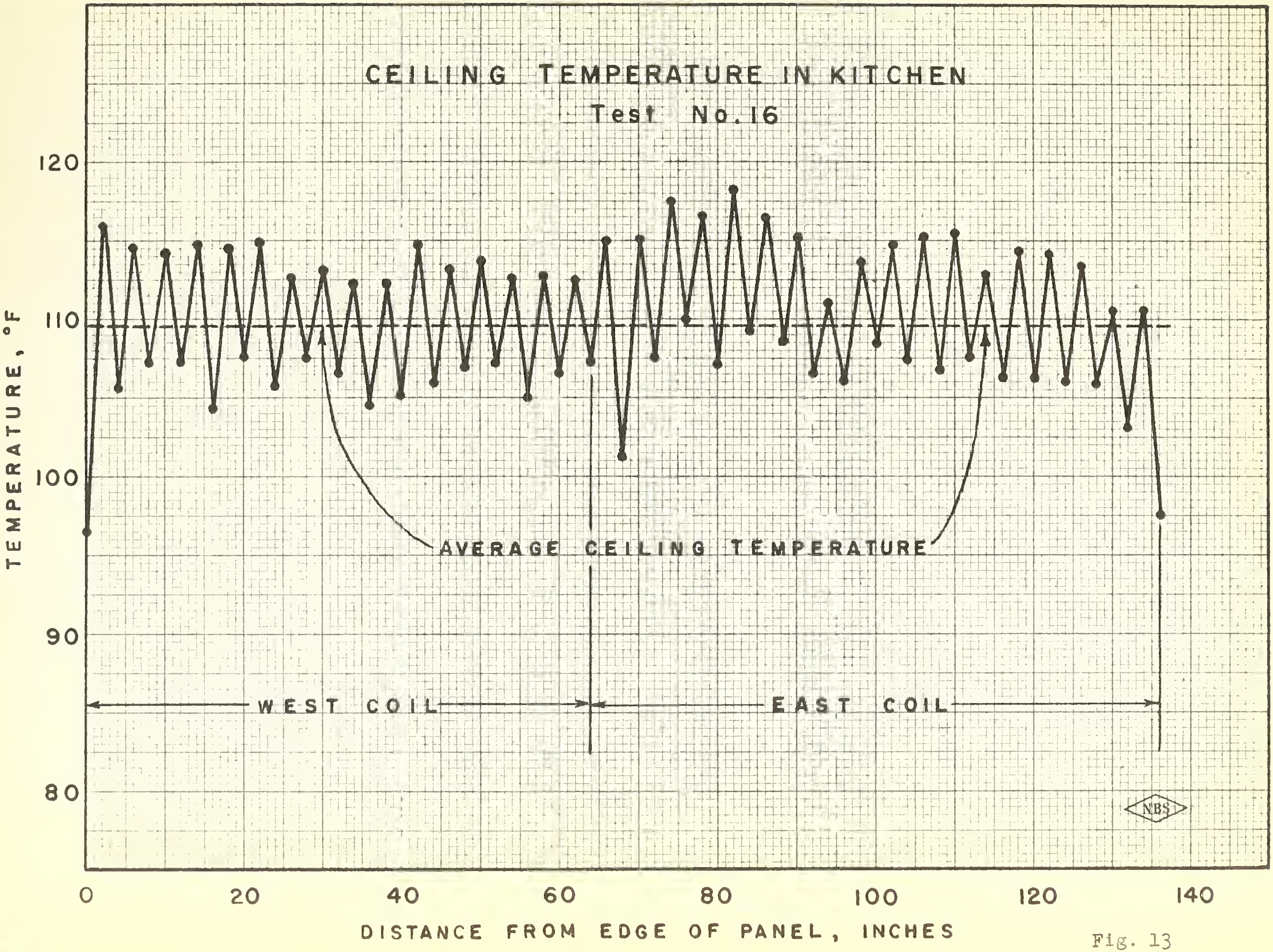

CEILING TEMPERATURE IN KITCHEN
Test No. 16
120
110
100
90
80
TEMPERATURE, °F
AVERAGE CEILING TEMPERATURE
WEST COIL
EAST COIL
NBS
0
20
40
60
80
100
120
140
DISTANCE FROM EDGE OF PANEL, INCHES

Fig. 13

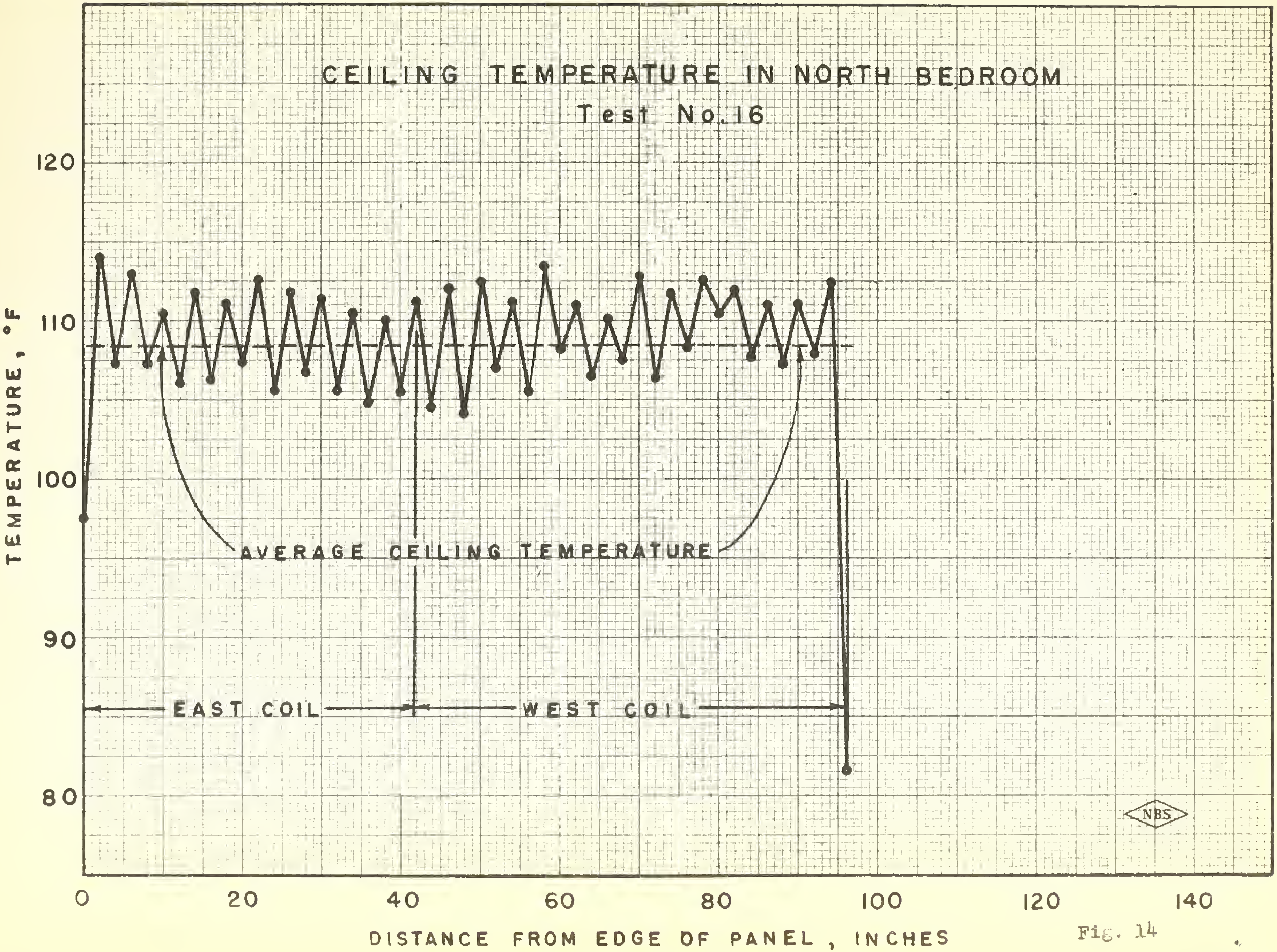
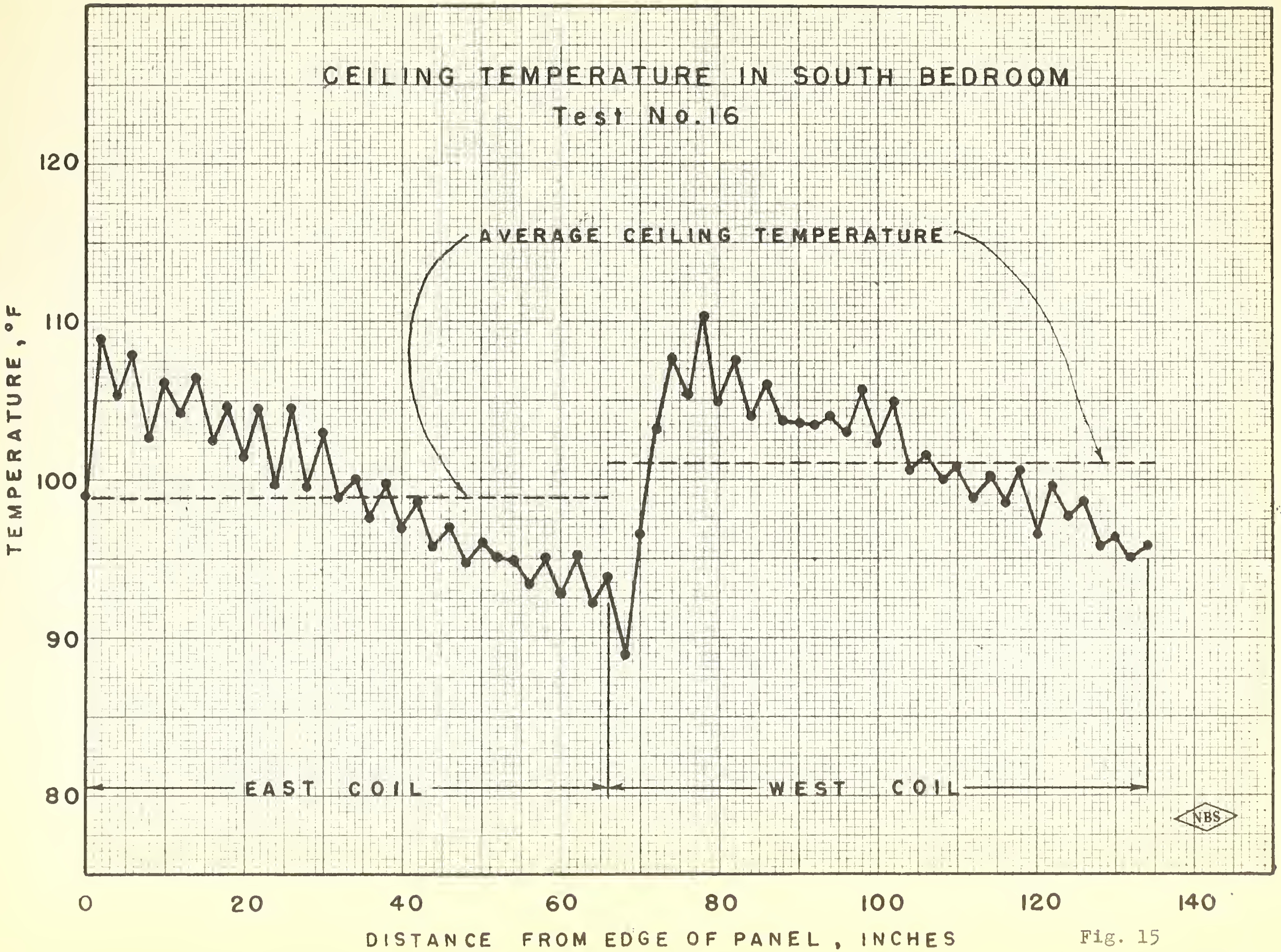

CEILING TEMPERATURE IN NORTH BEDROOM
Test No. 16
120
110
100
90
80
TEMPERATURE, °F
AVERAGE CEILING TEMPERATURE
EAST COIL
WEST COIL
NBS
0
20
40
60
80
100
120
140
DISTANCE FROM EDGE OF PANEL, INCHES

Fig. 14


CEILING TEMPERATURE IN SOUTH BEDROOM
Test No. 16
AVERAGE CEILING TEMPERATURE
EAST COIL
WEST COIL
TEMPERATURE, °F
120
110
100
90
80
0
20
40
60
80
100
120
140
DISTANCE FROM EDGE OF PANEL, INCHES
NBS
Fig. 15

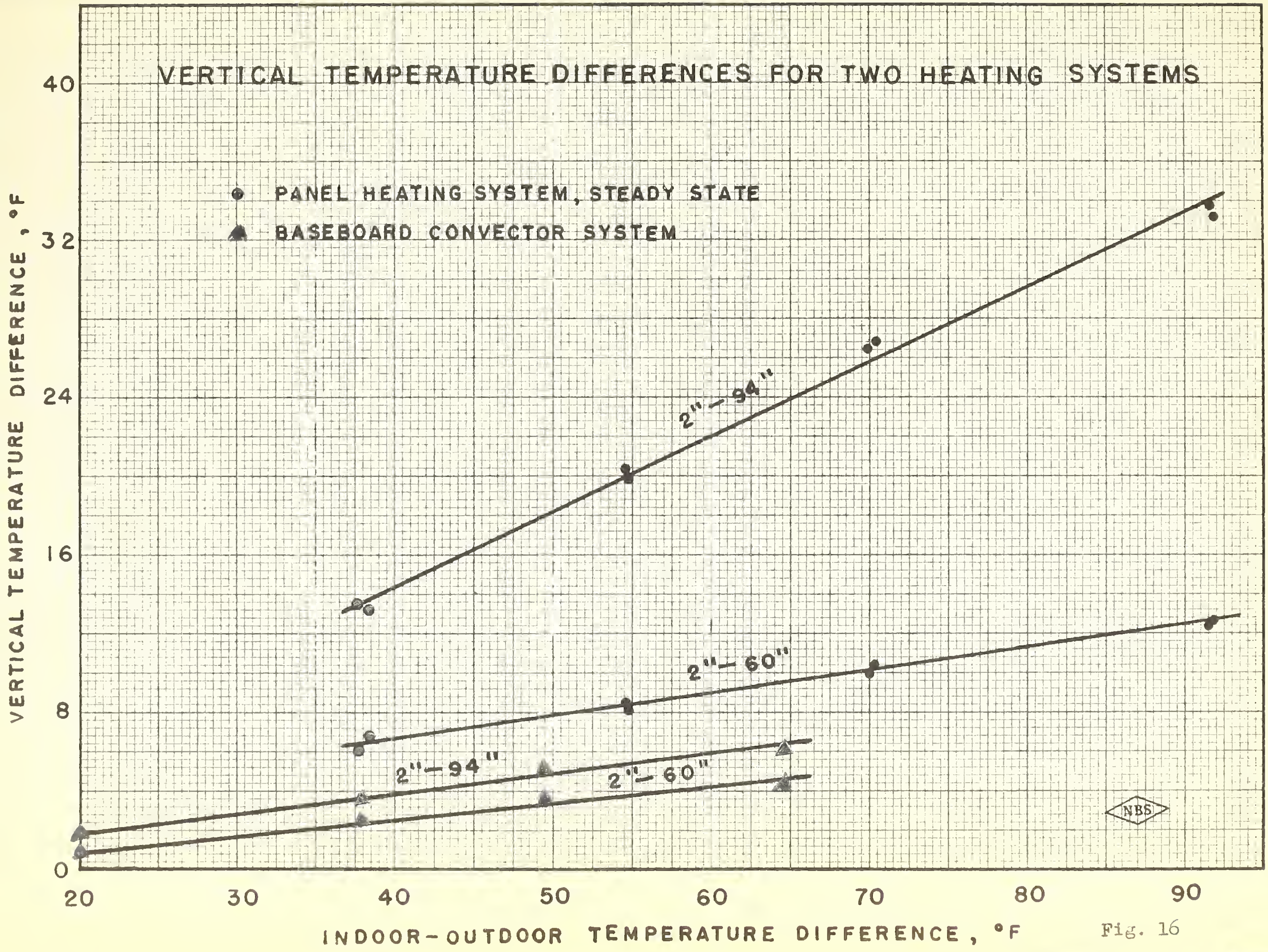

VERTICAL TEMPERATURE DIFFERENCES FOR TWO HEATING SYSTEMS
PANEL HEATING SYSTEM, STEADY STATE
BASEBOARD CONVECTOR SYSTEM
2"—94"
2"—60"
2"—94"
2"—60"
NBS
VERTICAL TEMPERATURE DIFFERENCE, °F
0
8
16
24
32
40
20
30
40
50
60
70
80
90
INDOOR-OUTDOOR TEMPERATURE DIFFERENCE, °F

Fig. 16

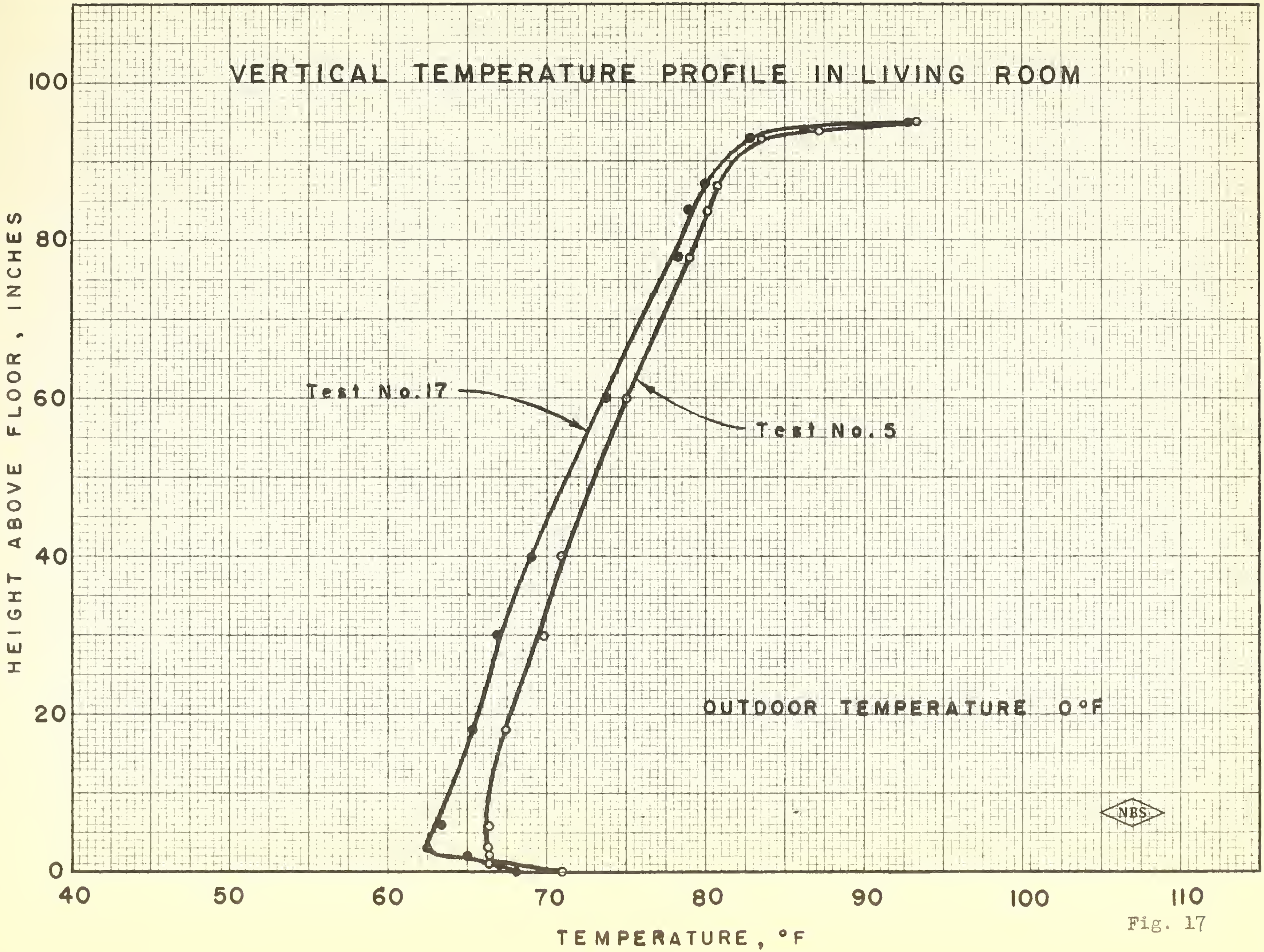
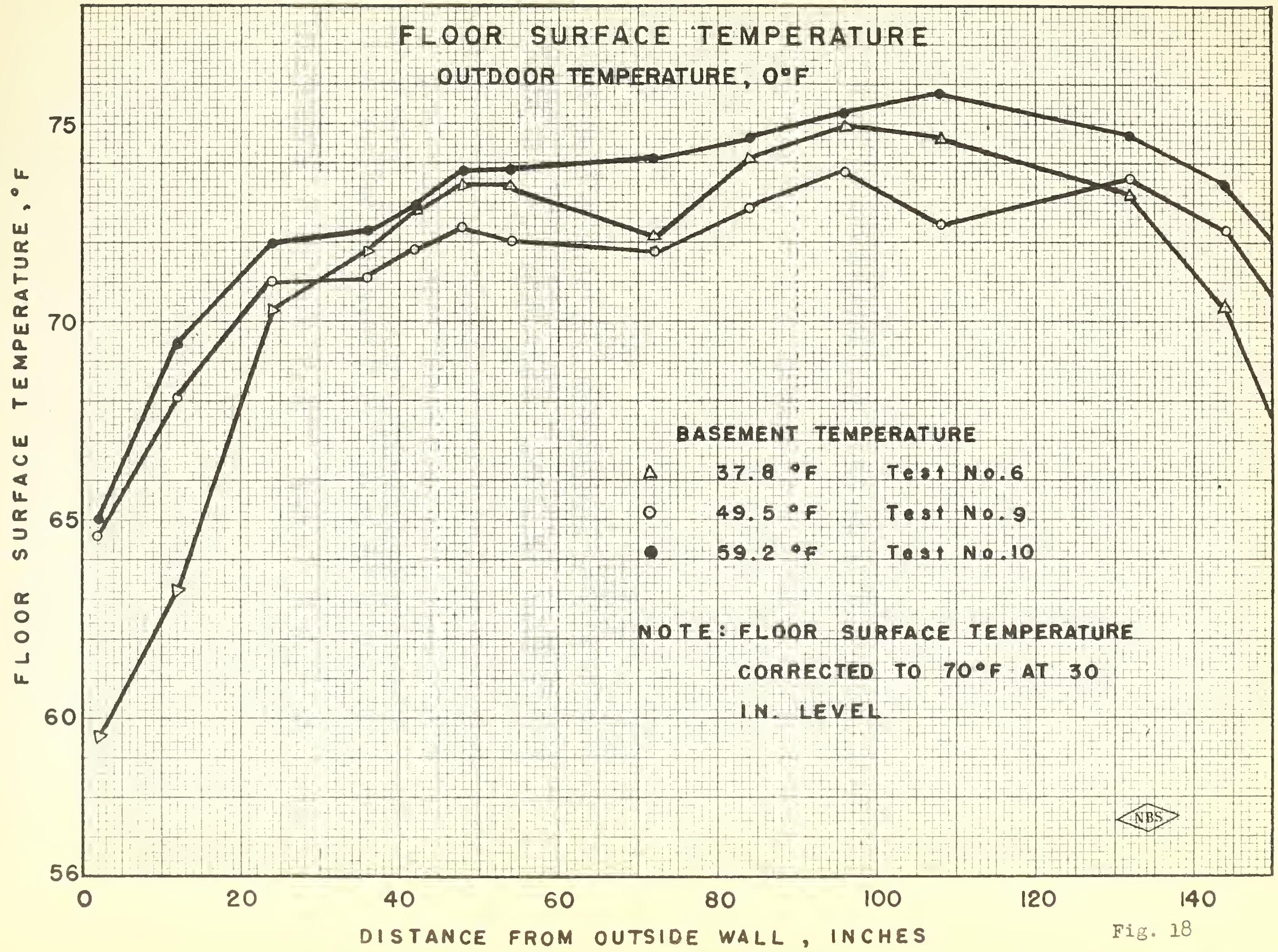
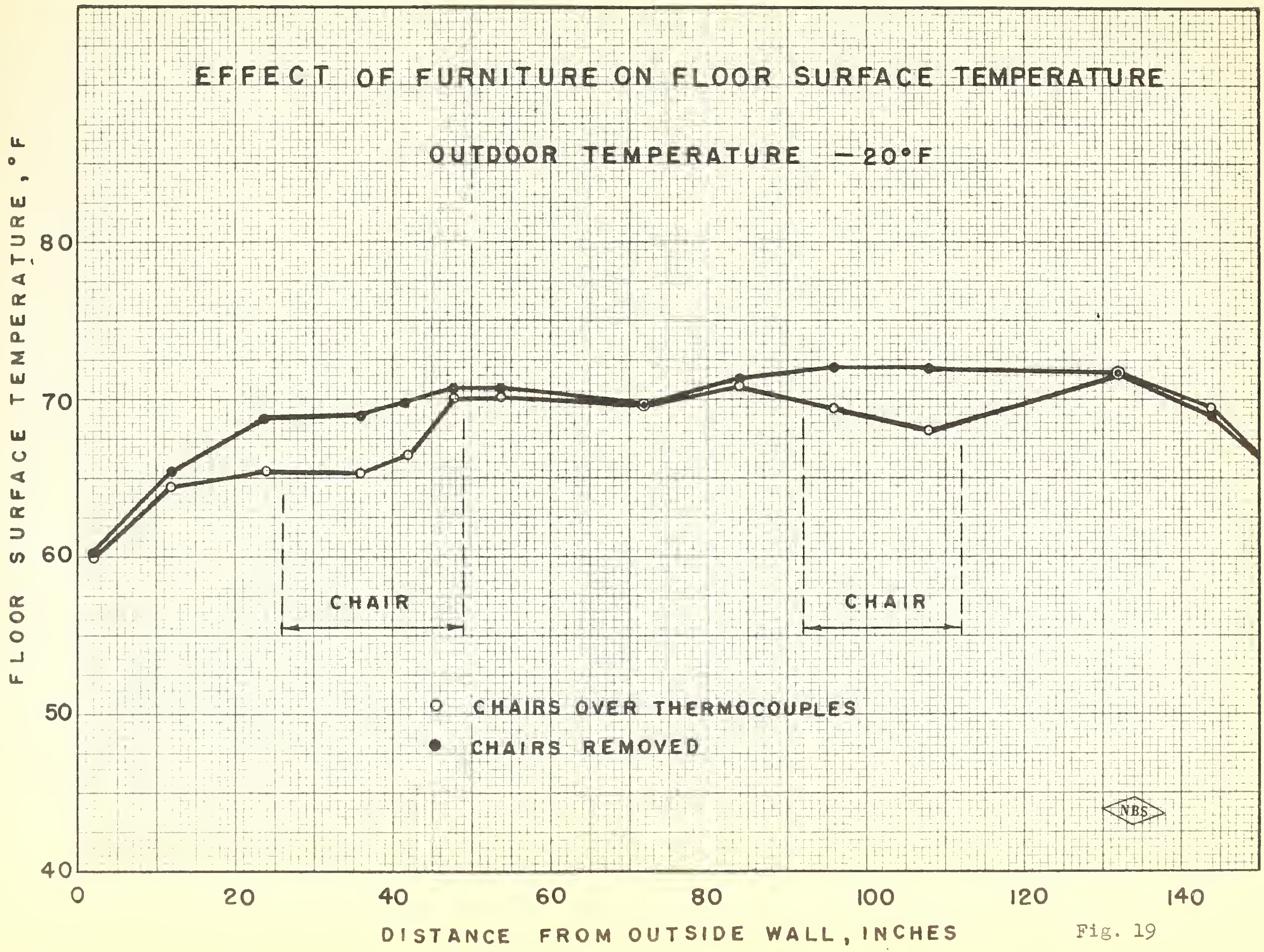

VERTICAL TEMPERATURE PROFILE IN LIVING ROOM
HEIGHT ABOVE FLOOR, INCHES
0
20
40
60
80
100
40
50
60
70
80
90
100
110
TEMPERATURE, °F
Test No. 17
Test No. 5
OUTDOOR TEMPERATURE 0°F
NBS

Fig. 17



FLOOR SURFACE TEMPERATURE
OUTDOOR TEMPERATURE, 0°F
BASEMENT TEMPERATURE
37.8 °F Test No.6
49.5 °F Test No.9
59.2 °F Test No.10
NOTE: FLOOR SURFACE TEMPERATURE CORRECTED TO 70°F AT 30 IN. LEVEL
NBS
75
70
65
60
56
0
20
40
60
80
100
120
140
FLOOR SURFACE TEMPERATURE, °F
DISTANCE FROM OUTSIDE WALL, INCHES

Fig. 18



EFFECT OF FURNITURE ON FLOOR SURFACE TEMPERATURE
OUTDOOR TEMPERATURE -20°F
FLOOR SURFACE TEMPERATURE, °F
40
50
60
70
80
0
20
40
60
80
100
120
140
DISTANCE FROM OUTSIDE WALL, INCHES
CHAIR
CHAIR
CHAIRS OVER THERMOCOUPLES
CHAIRS REMOVED
NBS

Fig. 19

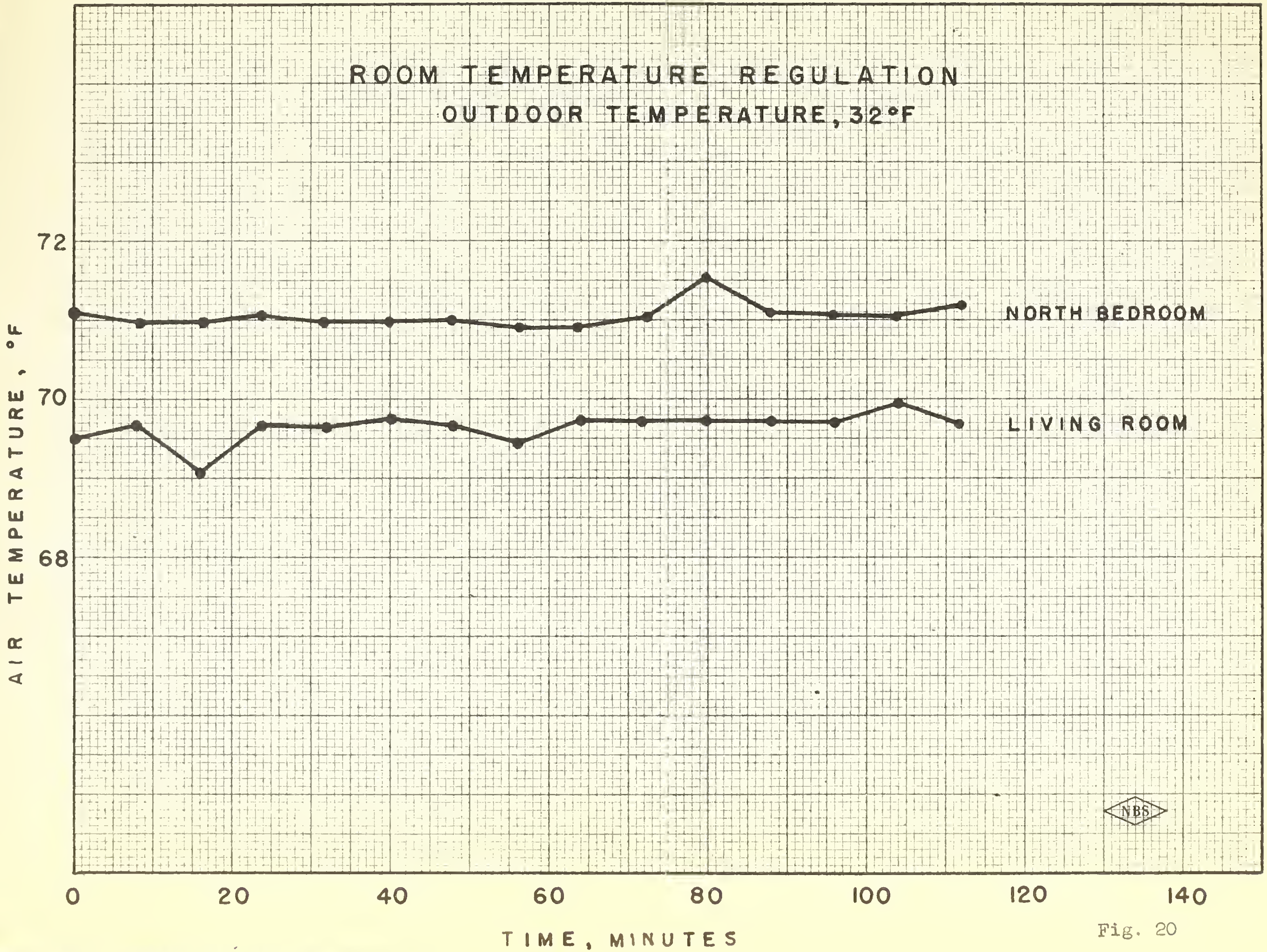

ROOM TEMPERATURE REGULATION
OUTDOOR TEMPERATURE, 32°F
NORTH BEDROOM
LIVING ROOM
AIR TEMPERATURE, °F
72
70
68
0
20
40
60
80
100
120
140
TIME, MINUTES
NBS

Fig. 20

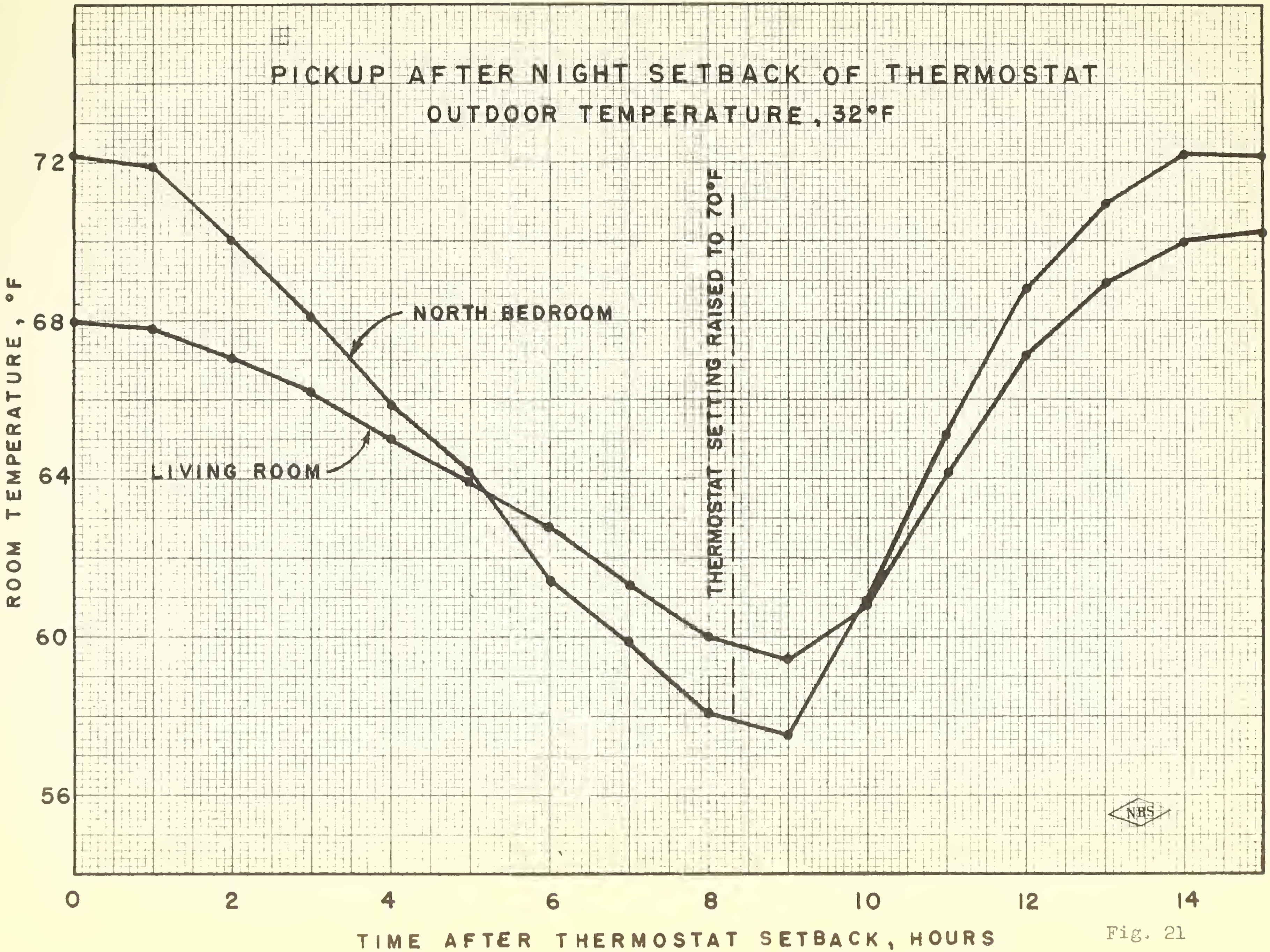

PICKUP AFTER NIGHT SETBACK OF THERMOSTAT
OUTDOOR TEMPERATURE, 32°F
NORTH BEDROOM
LIVING ROOM
THERMOSTAT SETTING RAISED TO 70°F
ROOM TEMPERATURE, °F
72
68
64
60
56
0
2
4
6
8
10
12
14
TIME AFTER THERMOSTAT SETBACK, HOURS
NBS

Fig. 21

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures: advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations: the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS